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Water and Power from Geothermal Resources in California

AN OVERVIEW

State of California
The Resources Agency
Department of Water Resources

(COVER)

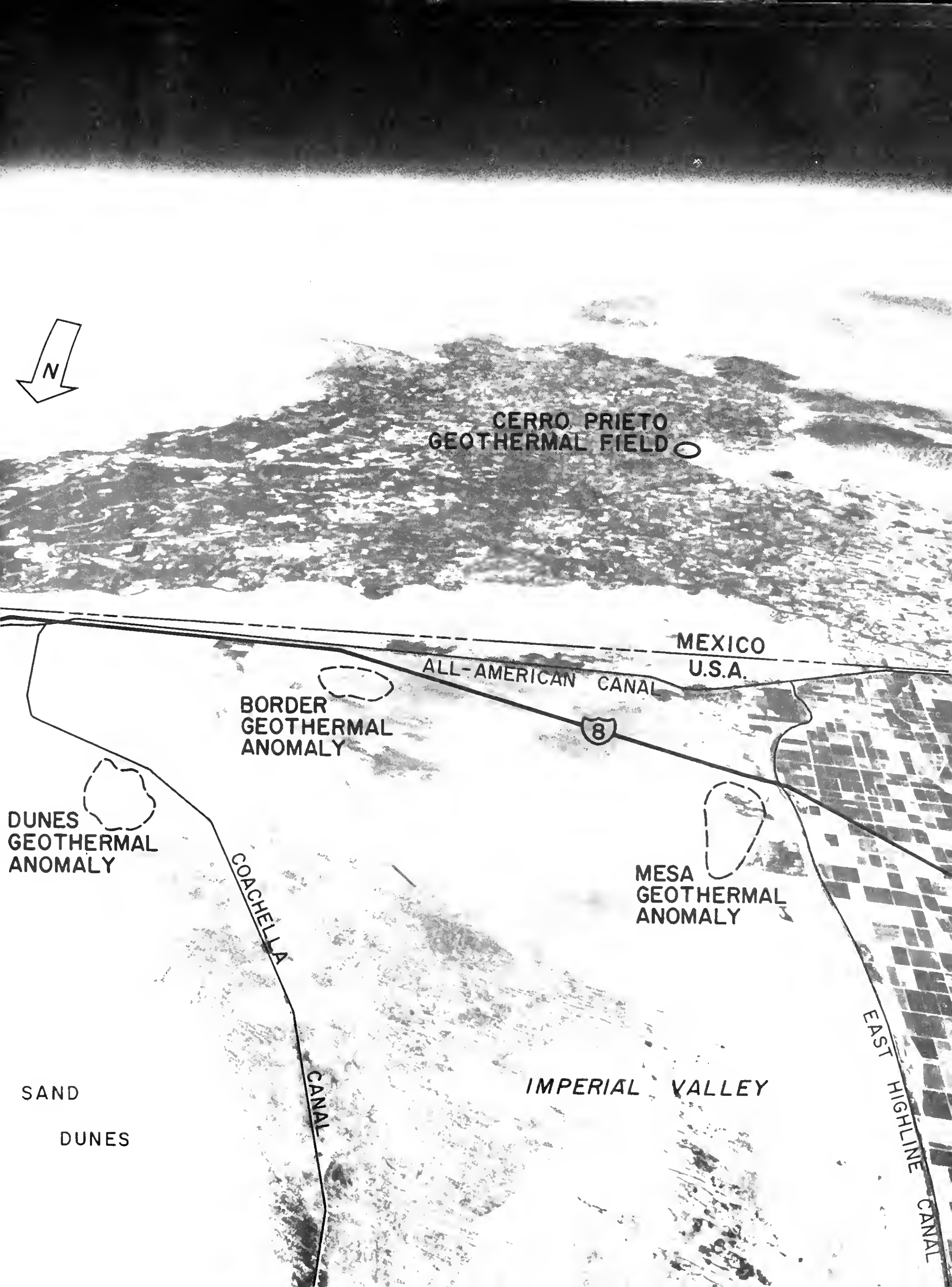
The first two units of the electric generating plant powered by geothermal steam at The Geysers in Sonoma County, California. These two units have a combined capacity of 24,000 kilowatts. Total capacity at The Geysers is at present 396,000 kilowatts.

--Pacific Gas and Electric Company photo

(OPPOSITE PAGE)

Southern tip of Imperial Valley, California, looking into the Mexicali Valley of Mexico. The locations of three of the geothermal hot spots, or anomalies, in the Imperial Valley and the Cerro Prieto, Mexico, geothermal field can be seen in this photograph.

--USAF photo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CERRO PRIETO
GEOTHERMAL FIELD
MEXICO
U.S.A.
ALL-AMERICAN CANAL
BORDER
GEOTHERMAL
ANOMALY
8
DUNES
GEOTHERMAL
ANOMALY
COACHELLA
CANAL
MESA
GEOTHERMAL
ANOMALY
EAST HIGHLINE
CANAL
IMPERIAL VALLEY
SAND
DUNES

FOREWORD

Geothermal resources, which appear to be widespread and plentiful in California, have the potential for solving some of our energy and water problems. Electrical energy can be produced from geothermal steam in an environmentally acceptable way, as has been demonstrated on a commercial scale at The Geysers in Sonoma County. The hot water can be demineralized without adding heat. Minerals too could be obtained if they can be separated out economically.

Why then has development been slow in spreading? To what extent can this resource be looked to as an economical source of water supply? What are the obstacles involved? What can be done to help overcome them?

This report provides some answers to these questions. It gives an overview of what is known about the geothermal resources. It also identifies the problems that have appeared and describes the efforts being made to overcome them.

The Department of Water Resources, in addition to conducting its own geothermal studies, will continue to monitor and evaluate the studies of others. The information so obtained will provide a basis for comparing geothermal development with other alternative sources of water and energy.

John R. Teerink

John R. Teerink, Director
Department of Water Resources

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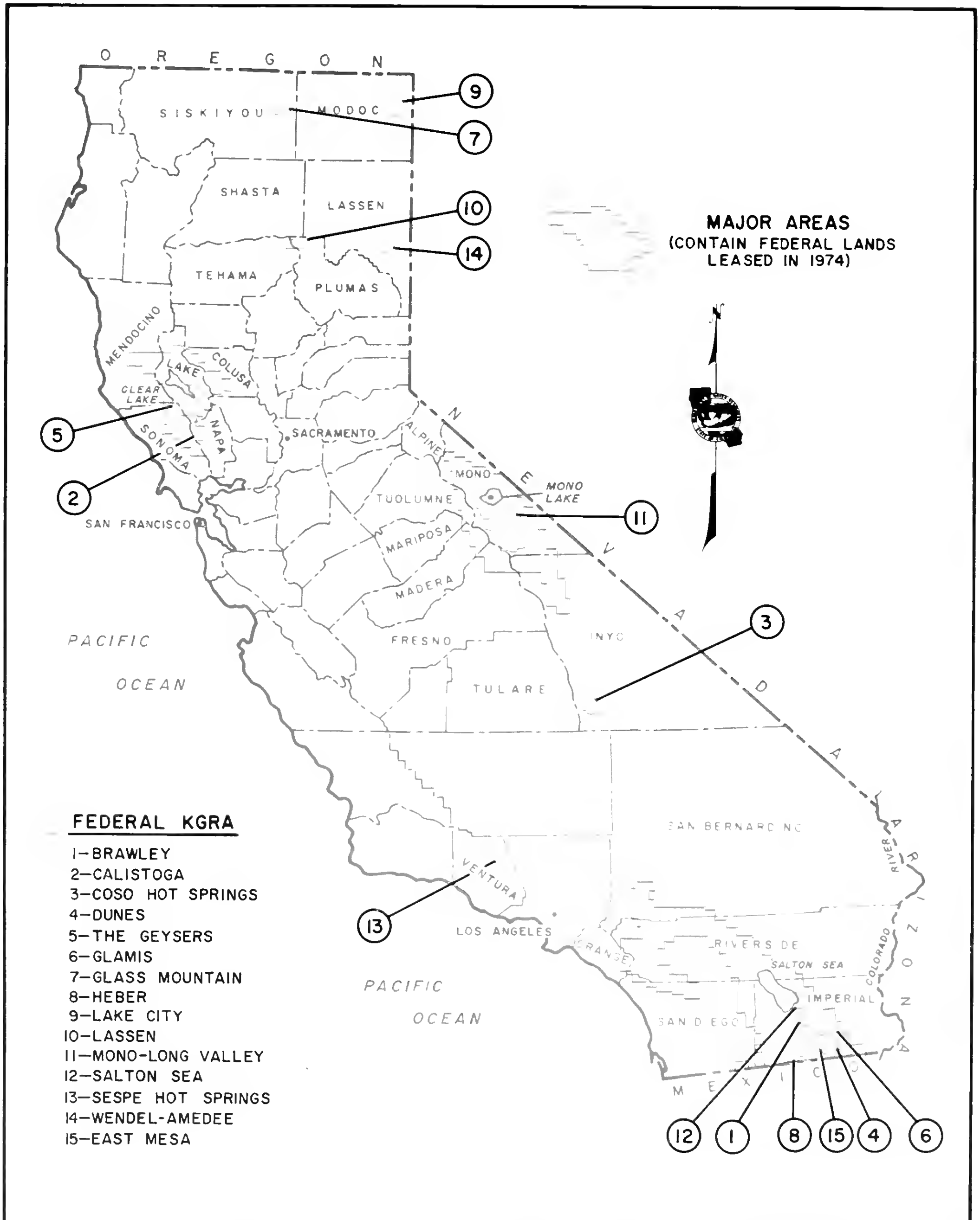


Figure 1—LOCATIONS OF PRINCIPAL KNOWN GEOTHERMAL RESOURCE AREAS (FEDERAL KGRA) IN CALIFORNIA

I. WHY ARE WE INTERESTED IN GEOTHERMAL RESOURCES?

For centuries, people have known that the water in certain springs was naturally heated, and many persons have suspected that, somewhere deep within the earth, nature was generating energy and was hoarding a water supply, both of which were largely untapped. But only in recent years have the tools been available with which to begin probing this geothermal ("earth heat") resource. Giving impetus to the quest today is the general realization that the supplies of energy from conventional sources and the supplies of fresh water from easily accessible sources are being used at an increasingly rapid rate.

The United States and California in particular have been blessed with sizable reserves of the geothermal resource. In 1971, the U. S. Geological Survey designated more than 1 million acres of land in California as Known Geothermal Resources Areas (Federal KGRA). The sites are shown on Figure 1.

To encourage and facilitate the development of the geothermal resource, the Congress in 1970 passed a Geothermal Steam Act establishing a leasing system for federal lands. In January 1974, competitive bids for leases of federal land in three areas in California were opened for the first time under this act. The three areas are:

- o The Geysers in Sonoma County where, for a number of years, electrical energy has been successfully produced from the geothermal resources;
- o The Mono Lake-Long Valley-Casa Diablo area centered in Mono County; and
- o The Imperial Valley in Imperial County, where the State's largest geothermal reserves have been found.

Purpose of Report

The California Department of Water Resources realizes that, if the geothermal resource is to be effectively used without unexpected or undue adverse effects, a better understanding by the public and its officials regarding the possible roles of this resource in meeting water and energy demand is necessary. Therefore, this report has been prepared with the objective of summarizing, in a generalized format, the nature of and the development problems and issues relating to California's geothermal resources.

Scope of Report

Although the report deals with the geothermal resources in the State as a whole, aspects of the resources in the Imperial Valley are frequently discussed as examples of the general cases. This

> **WHAT ARE GEOTHERMAL RESOURCES?**
>
> Recognizing that the geothermal resource is more than just a "superheated" water or naturally produced steam, the California Legislature in 1967 incorporated the following definition of geothermal resources in the State's Public Resources Code.
>
> "The natural heat of the earth, the energy, in whatever form, below the surface of the earth present in, resulting from, or created by, or which may be extracted from, such natural heat, and all minerals in solution or other products obtained from naturally heated fluids, brines, associated gases, and steam, in whatever form, found below the surface of the earth, but excluding oil, hydrocarbon gas or other hydrocarbon substances."

is done because the Imperial Valley contains what is estimated to be the greatest geothermal reserve of the State, because intensive, multiagency studies are under way in that area, and because the type of geothermal resource it contains is typical of the type found in most of the known geothermal areas today.

Information is included on the physical characteristics of the different types of development methods and problems, environmental concerns, and legal and institutional aspects. Because the legal and institutional aspects are becoming increasingly significant, Appendix A, which expands the discussion in the report, is included for more detailed study.

In preparation of this report, the work of a number of private and public agencies was relied upon. A list of documents consulted is given in Appendix B.

II. WHAT DO WE KNOW ABOUT GEOTHERMAL RESOURCES?

A clue to the phenomenon that results in geothermal resources is found in the measurements of heat that have been taken in deep mines and wells. In general, the temperatures in the earth's crust tend to increase as the depth increases. Normally, the increase is 1° to 2° F. with each 100 feet of depth--about 0.5° to 1° C. per 30 meters of depth. At some places, however, the increase is much greater, and high temperatures are reached at shallow depths. These "hot spots" have come to be known as geothermal anomalies.

The location of these geothermal anomalies may be marked by the presence of hot springs, steam vents, geysers, or other volcanic activity--but in some cases there may be no surface indication (Figure 2).

Theory of Origin

The recently developed plate tectonic concept, which is now generally accepted by earth scientists, appears to offer an explanation for the origin of these geothermal anomalies. Proponents of this theory contend that the earth's surface consists of a number of plates of crust which "float" on a layer of molten rock. Individual plates may cover as much as several million square miles or square kilometers.

As a result of forces that are as yet little understood, the plates move about, separating, colliding, and jostling each other. The rate at which this movement takes place has been estimated as 0.4 to 4.4 inches (1 to 11 centimeters) per year.

When the plates collide, one of three kinds of interaction can take place. In head-on collisions at velocities of less than 1.5 inches (4 centimeters) per year, the leading edges of the plates are compressed, distorted, and crumpled to form complex mountain ranges. The Alps and Himalayas are believed to have been created by such collisions between plates.

At greater velocities, collisions can result in one plate riding over another. The lower plate is bent and thrust downward into the underlying molten rock, where it is melted and absorbed into the earth's mantle. The great ocean deeps, island arcs, and chain of

One of many hot springs in Modoc County, California. This one is near Adin.

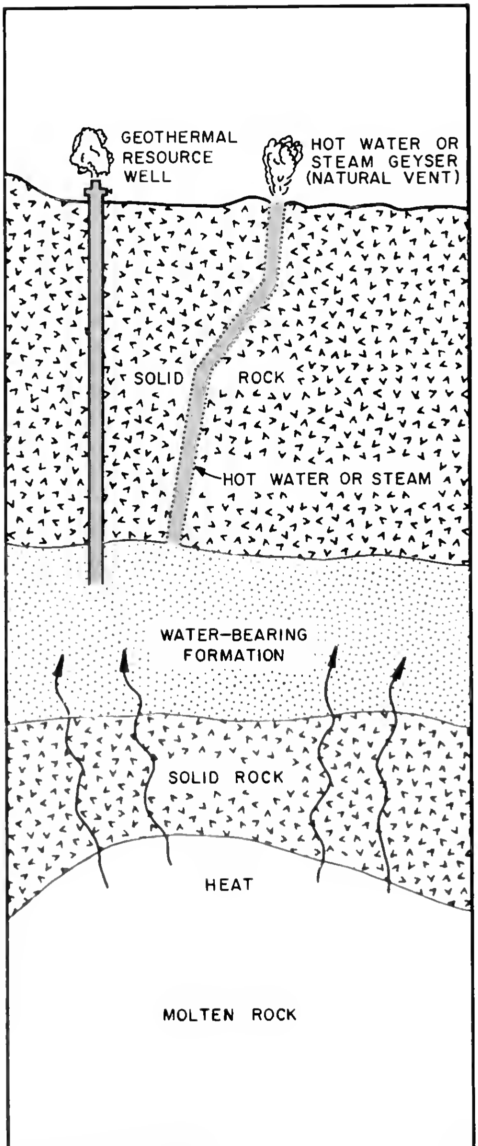


Figure 2—CROSS SECTION OF GEOTHERMAL ANOMALY

volcanoes known as the "ring of fire" (Figure 3) are physiographic features attributed to such crustal overlapping.

In the third kind of collision, plates meet obliquely and grind against each other. This type of contact is exemplified by the San Andreas fault of California, which marks the juncture between the Pacific and American plates. Under this theory, the earthquakes generated by the San Andreas fault are the vibrations released as these two great plates rub against each other.

The contacts between crustal plates are therefore lines of tension, compression, or friction. They are frequently marked by volcanism as a result of molten rock that has risen between the plates or as a result of heat generated by collision of the plates. In either case, heat is present and is transmitted by conduction into surrounding crustal formations. These heated areas are the geothermal anomalies with which we are concerned.

Types of Resources

The geothermal anomalies may contain steam, hot water, a combination of steam and hot water, or neither. Those that contain primarily steam are referred to as "vapor dominated", those that contain primarily hot water are "hot water dominated", and those that contain very little water or steam are the "hot rock" type. The hot water-dominated type is found in the highest percentage of the geothermal areas known today.

Experience has shown that geothermal water tends to be more mineralized than is nongeothermal ground water, probably because at high temperatures it more readily dissolves salts from the rocks that surround it. (Salts, as used here, include sodium chloride--ordinary table salt--plus a number of other minerals. Therefore, in this report, "minerals" and "salts" mean the same thing. To measure the

salts, or minerals, dissolved in a liquid, the content of total dissolved solids--TDS--is measured. Table 1 shows comparative TDS content of a number of liquids.)

Types Found in California

California contains geothermal anomalies of all types. Those found at The Geysers are predominately vapor dominated and those in the Mono Lake-Long Valley-Casa Diablo area and the Imperial Valley are mainly hot water dominated.

Conditions in Imperial Valley

Some of the geothermal water and steam extracted in the Imperial Valley has been found to be even more salty than ocean water. A possible explanation for this lies in the physical character of the valley itself.

The Imperial Valley occupies a portion of the Salton Trough, which is a northwesterly-trending depression that extends from the Gulf of California on the south to San Gorgonio Pass, near Banning, on the north. The geothermal resources of the valley are contained in approximately 1,700 square miles (4,400 square kilometers). On the north end of Imperial Valley is the Salton Sea, which covers about 360 square miles (930 square kilometers) and has a surface elevation that is 232 feet (71 meters) below ocean level. The Salton Sea has no outlet.

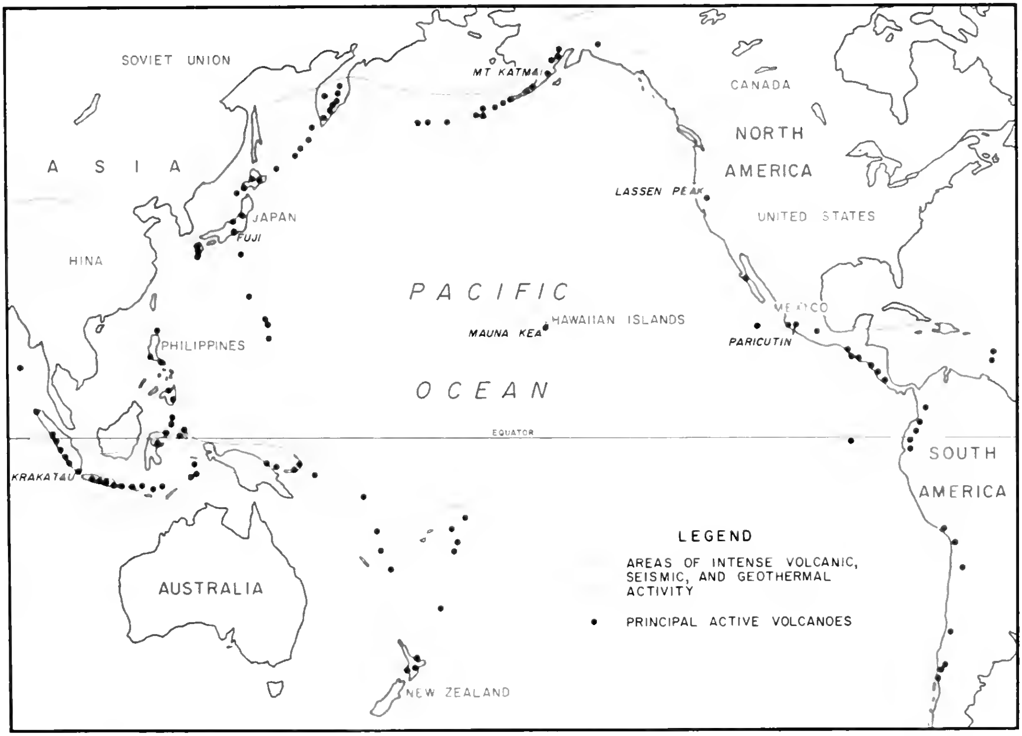


Figure 3—PACIFIC RING OF FIRE

TABLE I

SALT (TOTAL DISSOLVED SOLIDS) CONTENT OF VARIOUS WATERS

In milligrams per liter (mg/l)

Average ocean water	35,000
Recommended limit for drinking water	500*
Average in Salton Sea	38,000
Average of ground water in Imperial Valley	1,500
Average in Colorado River at present **	850
Average in Colorado River forecast for 2000 (without control measures) **	1,250
Average in Great Salt Lake, Utah	300,000
Geothermal water at Cerro Prieto, Mexico	13,000 – 25,000
Geothermal water at Buttes geothermal domain, Imperial Valley ♦	260,000
Geothermal water elsewhere in Imperial Valley ♦	3,000 – 20,000

* *State Department of Health will permit use of water of 1,500 mg/l under a temporary permit.*

***At Imperial Dam where water is diverted for irrigating agriculture in Imperial Valley. Concentrations are based on U. S. Bureau of Reclamation study reported in "Colorado River Water Quality Improvement Program", Feb. 1972*

♦ *Based on available records*

Rainfall in the Imperial Valley ranges from 2 to 5 inches per year (5 to 13 centimeters). The land in the valley is primarily either undeveloped desert or irrigated agriculture, with irrigation water supplied by means of canals from the nearby Colorado River.

The agricultural economy of Imperial Valley is greater than that of any other section of the United States, except the Central Valley of California. Because the Imperial Valley is virtually frost free, crops can be grown throughout the entire year. A network of more than 30 collector drains from the irrigation system in the valley empty into the Salton Sea. The drains were installed to maintain a favorable salt balance in the irrigated lands by collecting and carrying away salt-laden water that has percolated into the ground. They also aid in the prevention of waterlogging of the land by controlling the depth to the water table.

Two major streams, the Alamo River and the New River, also carry irrigation return water into the Salton Sea. Both originate in Mexico and flow north across the Imperial Valley.

As a result of its role as a sump into which highly salty waters have drained through the years, the Salton Sea has become so mineralized that its fishery is now being threatened.

The ground water (nongeothermal) in the valley, although not as mineralized as that of the Salton Sea, is of poorer quality than is water from the Colorado River. Little ground water is used for either agriculture or domestic purposes in the valley.

The Salton Trough has not only served as a collection point for water, but also through geologic time it has been a depository for sediments brought in by the water from upstream points such as the Grand Canyon. At various times,

the Colorado River has spilled over into the Imperial Valley. The most recent case was in 1905-07 when it created the Salton Sea.

The sedimentary deposits have served to entrap water, which has become geothermal brine. This brine is believed to have accumulated at comparatively shallow depth beneath the valley at nine geothermal anomalies (Figure 4).

On the basis of evidence derived by their own researchers or those in other agencies, the U. S. Geological Survey and the University of California at Riverside have made preliminary estimates of the volumes of geothermal brine in storage in the Imperial Valley. Both stress the need for additional research to confirm and refine their estimates.

The U. S. Geological Survey reports* that "total usable and recoverable water in storage is estimated to be 1.1 billion acre-feet" (1,350 cubic kilometers). Further, it says, "the total estimated usable water in storage having a temperature of 150° C. or more (302° F.) is rounded to about 200 million acre-feet" (250 cubic kilometers). (The definition given for "usability of water in storage" is that the water is no saltier than ocean water, regardless of the concentration of specific constituents.) The estimates of the University of

*"Preliminary Appraisal of Ground Water in Storage with Reference to Geothermal Resources in the Imperial Valley Area, California" by L. C. Dutcher et al. Geological Survey Circular 649, prepared in cooperation with the U. S. Bureau of Reclamation, 1972.

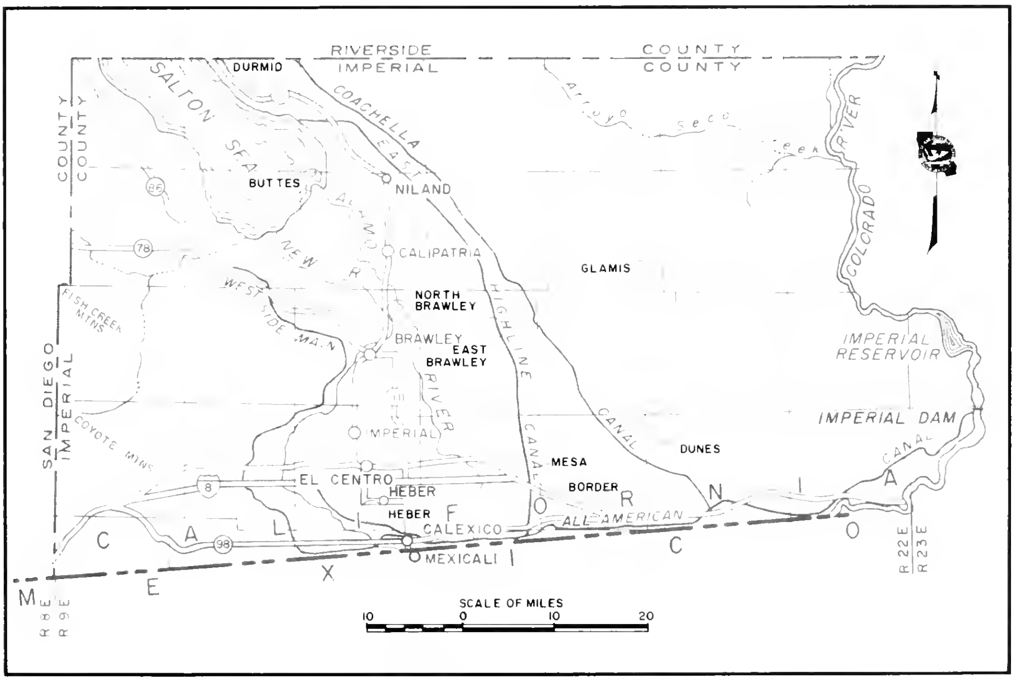


Figure 4 - LOCATION OF GEOTHERMAL ANOMALIES WITHIN IMPERIAL VALLEY

California at Riverside are larger--1.6 to 4.8 billion acre-feet (2,000 to 6,000 cubic kilometers) of geothermal brine in storage. Its estimate of the amount that is feasible to extract each year is 10 to 15 million acre-feet (12 to 18 cubic kilometers). Although other investigators have indicated they believe the potential is not that large, they do feel that the amounts are significant enough to merit additional study.

III. CAN WE GET WATER AND POWER FROM GEOTHERMAL RESOURCES?

Three products from geothermal resources suggest themselves immediately--electrical power, fresh water, and minerals. Although the main interest today is in the first two of these, history tells us that man's first commercial product from geothermal resources was minerals.

More recently, the conversion of geothermal energy to electrical power has become a commercial reality at several places in the world. Although the commercial production of fresh water from geothermal brines has not yet been attempted, the desalting of ocean water and brackish water has been successfully demonstrated by several different methods.

History of Development

Minerals. As early as 1260, sulphur, vitriol, and alum were being removed from the "lagoni" (hot steam geysers) of the Larderello district of Italy, and merchants of the district were actively trading these products with the Republic of Tuscany.

In 1812 the first attempts were made at Larderello to produce boric acid (in the anhydrous form) commercially by boiling down the geothermal brines in iron cauldrons heated with wood fuel and then crystallizing the final product in wooden barrels. The process was refined in 1827, when geothermal steam was substituted for wood fuel to accomplish the evaporation.

In the following decades, numerous wells were drilled to provide both the brine for boiling and the steam for heat. The ensuing increase in markets and production resulted in an international industry that lasted into the early part of this century. Within the past two decades, however, the discovery of more economical sources of boric acid, which was the

Larderello, Italy, where the first successful attempt was made to generate electrical energy from the geothermal resource. The geothermal facilities are in the background of the picture near the cooling towers.

principal product at Larderello, has halted the use of the local brines.

In the Imperial Valley also, a great deal of effort has been expended to develop a mineral and chemical-extraction industry. From 1932 to 1954, more than 65 wells were drilled near the Salton Sea for the production of carbon dioxide for use in manufacturing dry ice. Because of the rising level of water in the Salton Sea, which inundated some of the wells, and because carbon dioxide is more economically available from other sources, operations at most of these wells have been abandoned.

Beginning in November 1957, various other interests have attempted to extract minerals from the geothermal brines in the Imperial Valley. Many of these operations have been discontinued because of corrosion and scaling problems plus a decrease in the market price of potash and the other minerals that were sought.

Among the commercial concerns that are still operating in the Imperial Valley are GEMCOR (formerly Western Geothermal Inc.), which is extracting brine from a well near Niland for the production of calcium chloride; Earth Energy (a subsidiary of Union Oil Company of California), which in 1964 constructed, near the Buttes geothermal anomaly, a pilot plant for separation and solar evaporation ponds for extraction of potassium and other salts; and Imperial Thermal Products (a subsidiary of Morton International, Inc.), which has constructed and is operating a pilot plant near the Buttes geothermal anomaly to evaluate the economics of generating electric power as well as recovering minerals from the brine.

Energy. Energy from geothermal resources was first used for generating electricity in 1904 at Larderello, Italy. Today, the harnessing of steam is highly developed at that field; the system has a capacity of about 365,000 kilowatts.

Unsuccessful attempts were made to produce electricity from geothermal resources in Japan in 1920, at The Geysers in California in 1922, and on Mullet Island in the Salton Sea in 1927. The attempt on Mullet Island failed because of difficulty encountered in handling of the steam and heated brines, the lack of pressure, and an insufficient volume of steam.

Attempts to harness power from geothermal energy were successful in New Zealand in 1925, but large-scale development did not take place until 1940.

In 1960, the first commercial success in producing electricity in the United States came at The Geysers. From the first unit with a capacity of 12,500 kilowatts, energy production has been substantially increased to the present capacity of 396,000 kilowatts. Present plans are to install additional equipment to increase capacity by 110,000 kilowatts each year until the field reaches maximum capacity, which is estimated to be more than 1 million kilowatts.

Attempts have also been made to harness the geothermal energy in the Mono Lake-Long Valley-Casa Diablo area. By 1962, 10 wells had been completed near Casa Diablo with depths ranging from 360 to 1,063 feet (110 to 324 meters). Although operations were suspended for several years, Magma Power Company has recently begun testing some of the wells again. Primary purpose of the tests is to discover the amount of corrosion and the variety and amount of scaling.

Near Mono Lake, Southern California Edison Company and its cooperating associates drilled two wells in the fall of 1971. But the holes were abandoned when temperatures of no more than 136° F. (58° C.) were found at the bottom of the holes.

In April 1973, Mexico began operation of an electrical generating station at

Cerro Prieto in Baja California. This field, which is about 20 miles (32 kilometers) south of the International Border, is in the Mexicali Valley, which is a southward extension of the Imperial Valley.

In the Imperial Valley, Magma Power Company and Chevron Oil Company, in a joint venture with San Diego Gas and Electric Company, had--at presstime--completed drilling five wells near Heber for the purpose of generating electricity. Tests are now being conducted to discover the amount and kind of scaling and corrosion.

Magma Power Company and San Diego Gas and Electric Company have also drilled five wells near Niland. The operation of these wells is still in an experimental stage.

Southern California Edison Company, Southern Pacific Land Company, and Phillips Petroleum Company are also conducting a joint research program that is designed to develop a method or methods of using the geothermal resources for generating electricity, for recovering usable minerals and chemicals, and for producing potable water. In addition, they plan to study the disposal of waste geothermal fluids by injecting them into the ground. Southern California Edison Company is also participating in a joint venture with Getty Oil Company to explore several areas in the Imperial Valley for potential electrical power production using geothermal energy sources.

Table 2 summarizes electrical generating activities in the world.

TABLE 2

SUMMARY OF POWER GENERATION USING GEOTHERMAL RESOURCES*

In kilowatts

Nation	Area	Capacity	Total
Italy	Larderello	365,000	
	Monte Amiata	25,000	390,000
United States	The Geysers**	396,000	396,000
New Zealand	Wairakei	160,000	
	Kaweran	10,000	170,000
Mexico	Cerro Prieto**	70,000	70,000
Japan	Matsukawa	20,000	
	Otake	13,000	33,000
Soviet Union	Pauzhetsk	6,000	6,000
Iceland	Namafjall	3,000	3,000
		TOTAL	1,068,000

**Adapted from a table published in "Geothermal Energy—Resources, Production, Stimulation", edited by Paul Kruger and Carel Otte, Stanford University Press, 1973*

*** As of December 1974*

In Iceland, geothermal resources have been successfully used for space heating since 1928. Many homes and industries throughout the country are being supplied with hot water. Around Klamath Falls, Oregon, and Boise, Idaho, geothermal heat is also being used for space heating.

Water. Of particular interest in Southern California is the possible desalting of geothermal brine to produce fresh water. Although research has just begun on this, it is expected to rely heavily on the results of demonstration projects involving various processes for desalting sea water.

All the processes require the expenditure of considerable amounts of energy to separate the water from the salt. However, geothermal brine, because it is already hot, would require less outside energy for desalting than would sea water. Of the three major geothermal areas in California that are being investigated for commercial development, only the Imperial Valley appears at this time to have the quantities of hot subsurface brine sufficient to support large-scale production of water.

The U. S. Bureau of Reclamation is conducting research related to production of water from geothermal brine in the Imperial Valley. On the Mesa geothermal anomaly, it has drilled five wells and has constructed a pilot desalting plant. The pilot plant consists of two test units, both involving distillation processes.

One is a multistage flash unit and the other is a vertical tube evaporator (Figure 5). The project's main purpose is to identify and solve the problems unique to desalting of brines by use of geothermal heat.

Additional Exploration

Exploration for geothermal resources has been undertaken in Kenya and Tanzania in Africa. The United Nations is sponsoring development of geothermal resources in a zone encompassing parts of Guatemala, Costa Rica, and El Salvador.

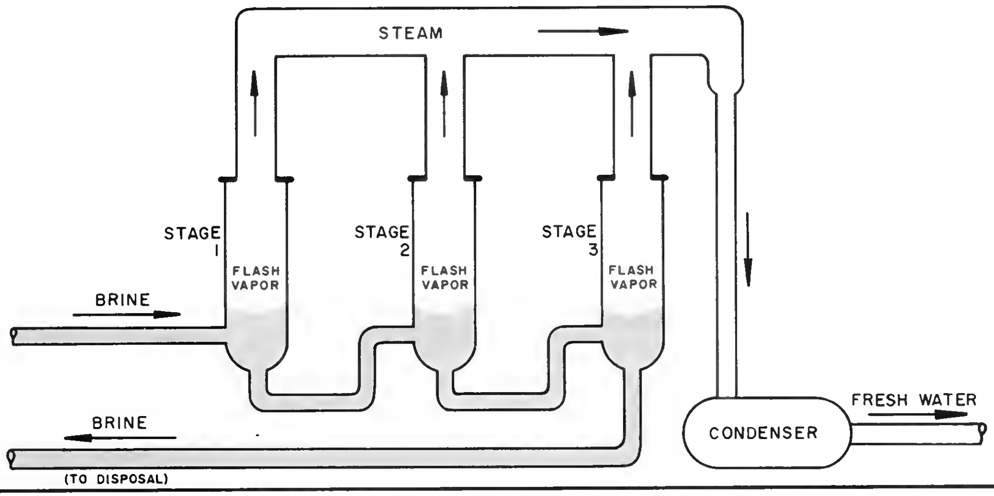
A number of governmental agencies--among them, the California Department of Water Resources, the University of California at Riverside, the U. S. Bureau of Reclamation, and the U. S. Geological Survey--have for the past several years been conducting investigations in the Imperial Valley in an effort further to define its geothermal anomalies.

The exploratory work done by the Department of Water Resources has been centered on the Dunes geothermal anomaly. In June 1972, a test hole was drilled to a depth of 2,000 feet (610 meters). Maximum temperature encountered in the test hole was 210° F. (103° C.). Cores, fluid samples, and logs from this well were collected and analyzed by both the Department and the University of California Riverside. Preliminary results of the findings were published in a joint report in 1973.

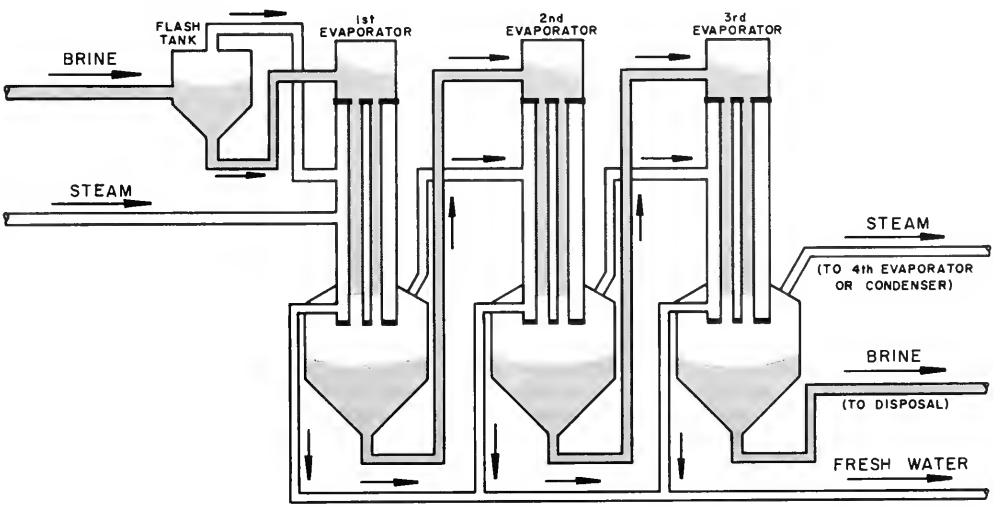
In addition, the University received a grant from the National Science Foundation to conduct further studies of the cores and fluid samples from the test hole in the Dunes geothermal anomaly.

The five wells drilled by the U. S. Bureau of Reclamation on the Mesa geothermal anomaly will also contribute to the general knowledge about the resource in Imperial Valley. In addition to desalting, such things as corrosion, scaling, and power production will also be studied. The first well was drilled in August 1972 to a depth of 8,030 feet (2,450 meters). Maximum temperature recorded was 400° F. (204° C.). The second was completed a year later and was drilled to a depth of 6,005 feet (1,830 meters). The maximum temperature recorded in this well was 370° F. (188° C.). Since then, three more wells have been drilled to a

Figure 5—SIMPLIFIED SKETCHES OF DISTILLATION PROCESSES FOR GEOTHERMAL BRINES



MULTISTAGE FLASH UNIT



VERTICAL TUBE EVAPORATOR

Department of Water Resources drill rig at the Dunes geothermal anomaly in Imperial Valley. The same type of equipment is used for drilling for oil, gas, and water. However, drilling for geothermal resources has necessitated the development of new techniques to cope with the exceptionally high subsurface temperatures.

depth of about 6,000 feet (1,830 meters) and have been perforated in the lower zones. One of these will serve as an injection well to receive waste geothermal fluid from the other four wells. At presstime, testing was still under way on the latter three wells.

In addition, a microearthquake monitoring system was temporarily installed by the University of California at Riverside, under contract to the Bureau of Reclamation, to obtain background data for studying effects of withdrawal and injection of water.

Both the U. S. Geological Survey and the University of California are continuing to collect and analyze the basic data needed for an accurate assessment of the size and characteristics of geothermal resources in the Imperial Valley.

The Geological Survey's study is part of a multidisciplinary research program, the objective of which is to understand the factors that control the nature and distribution of geothermal resources in the United States. Also under this program, a detailed study is being made of the hot water-type resource found in the Long Valley and the vapor-dominated resource in the Clear Lake area of California. In addition, research is being conducted on a number of specific problems in specific areas of the country.

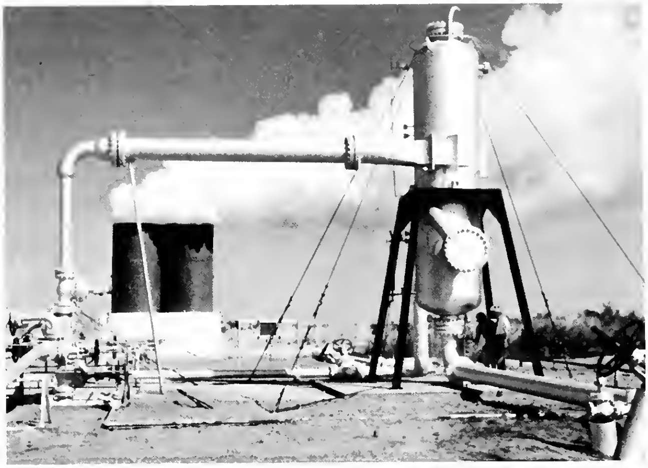
Production Methods

The methods used for the generation of electrical power, the production of fresh water, and the extraction of minerals and chemicals from each type of geothermal reservoir are discussed below.

Vapor-dominated Resource. As one would expect, geothermal anomalies in which the resource is vapor dominated are generally the most successful for generating electrical energy. However, the water condensed from the exhaust steam may carry mineral constituents such as boron that are harmful to sensitive plants. Also, the recovery of minerals from this type of resource is minimal and hence prohibitively expensive.

Control of the noncondensable gases is also an important consideration with the extraction of vapor-dominated resources. One such gas, hydrogen sulfide, is poisonous, has a disagreeable odor, is noxious to plants and animals, and is severely corrosive to the electrical apparatus.

Geothermal facilities at Cerro Prieto, Mexico. Steam and hot water from the well at the left are taken to the separator on the right. From there, the steam is conveyed by pipe to a generating plant.



In general, the use of vapor-dominated resources calls for routing the steam from the well through a separator to a turbo-generator. In the separator, impurities such as rock particles, dust, and condensate, which could damage the internal mechanism of the turbo-generator, are removed. Figure 6 illustrates the general method used for harnessing the power of vapor-dominated resources.

Water-dominated Resource. Hot water-dominated resources have not only a potential for producing electrical energy, but also for producing large quantities of fresh water and, if the amount of dissolved concentrates is sufficiently high, for producing marketable minerals and chemicals. Three methods of converting the hot brines in the Imperial Valley are under study.

The first is an open method that uses steam taken from the thermal water to run the turbo-generator. As the hot brine is brought to the surface, the pressure is reduced so that some of the water flashes to steam. The combination of steam and brine is routed to a separator from which the hot steam is directed to the turbo-generator to produce electricity. The exhaust steam from the turbine is sent to a condenser where it is cooled, condensed, and discharged. This method is illustrated on Figure 7.

The second method under test in the Imperial Valley is a closed method. In it, the hot brine and steam from a production well are conducted to a heat exchanger. Heat from the hot brine is transferred through the walls of the exchanger to another fluid (Freon and isobutane are two compounds that are commonly used), which then circulates in the closed cycle of the turbine. (An illustration of this method is given on Figure 8.)

As an alternative to these two methods, researchers at Lawrence Livermore Laboratory of the University of California have proposed that the total mass (steam plus hot brine) from geothermal production wells be used to run a specially designed turbo-generator. This would eliminate the need for the steam-brine separator in the dry steam method and the heat exchange reactor in the closed fluid method. Instead, the entire flow would be routed directly from the well through the turbine. Exhaust steam and brine leaving the turbine would be passed through a condenser for cooling and then discharged.

SIMPLIFIED SKETCHES OF METHODS FOR GENERATING

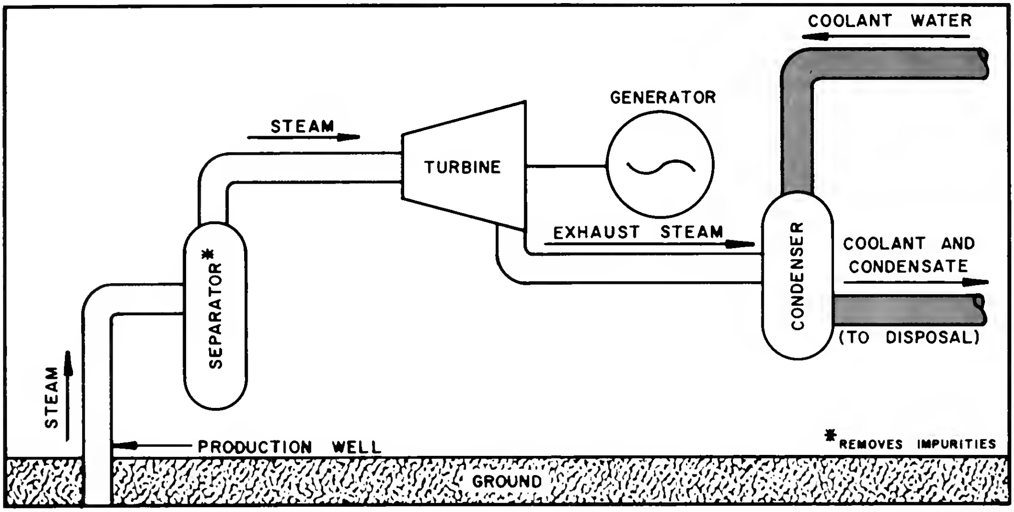


Figure 6—FROM VAPOR-DOMINATED RESOURCE

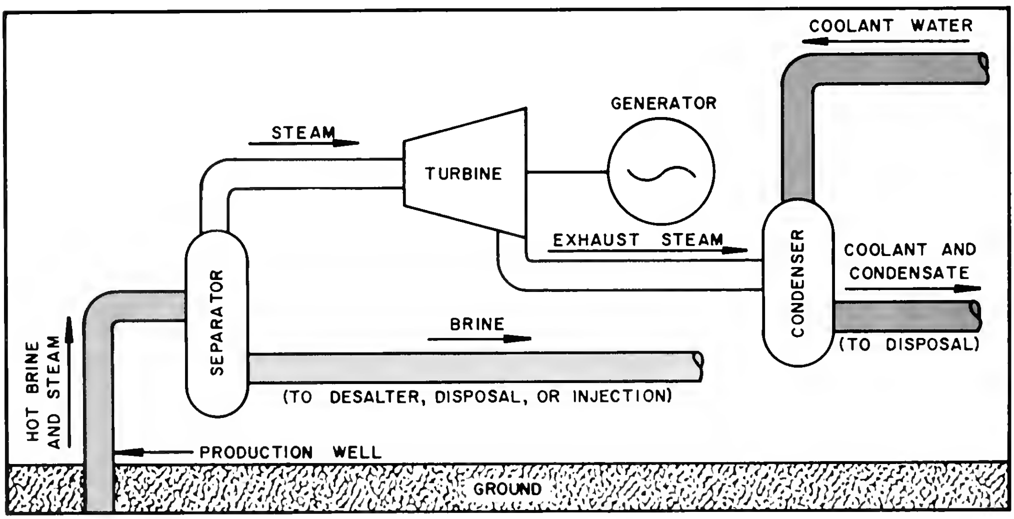


Figure 7—FROM WATER-DOMINATED RESOURCE: OPEN METHOD

POWER FROM GEOTHERMAL RESOURCES

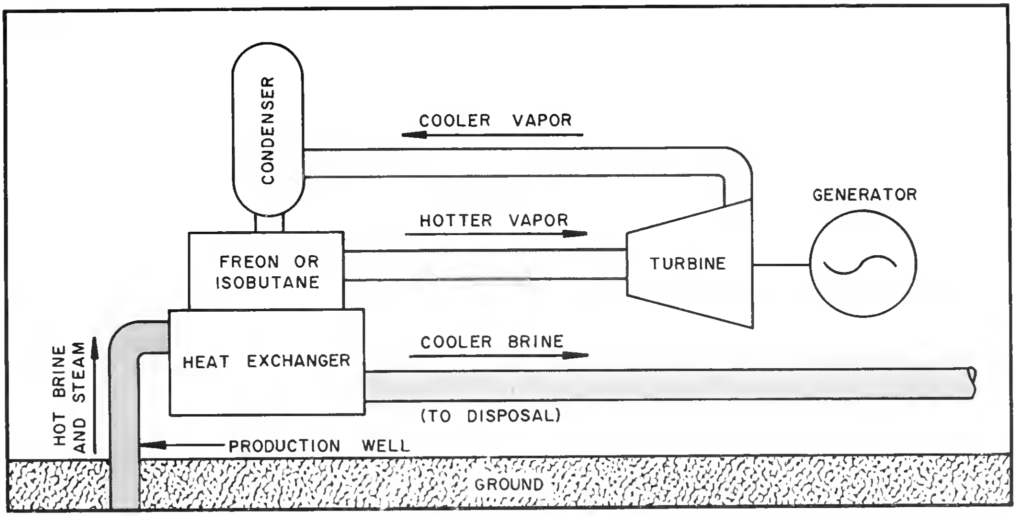


Figure 8 – FROM WATER-DOMINATED RESOURCE: CLOSED METHOD

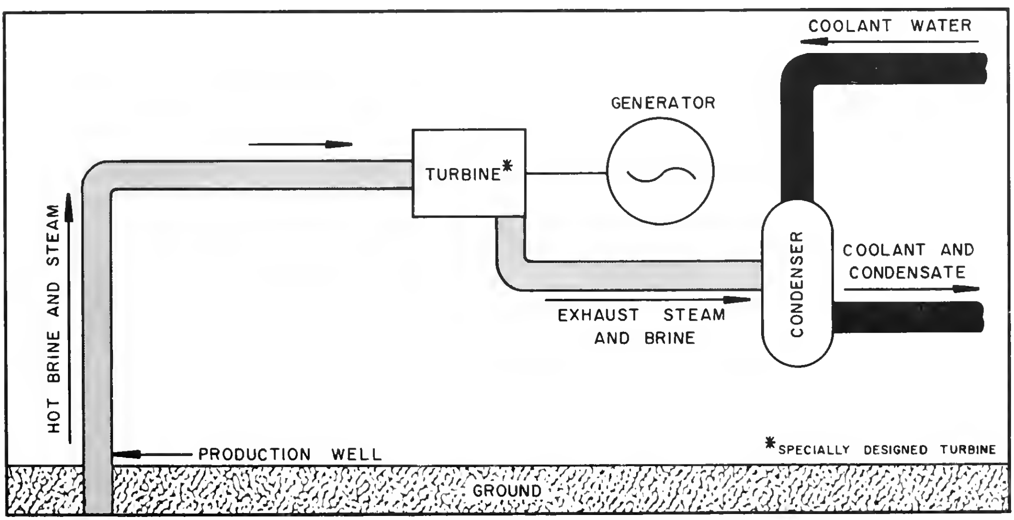


Figure 9 – FROM WATER-DOMINATED RESOURCE: TOTAL MASS METHOD

Figure 9 contains an illustration of this method.

Regardless of which of the three methods is used, the brines produced could be sent to a desalting unit for the production of fresh water, and the highly concentrated waste from the desalter could be further processed for the extraction of minerals and chemicals.

Hot Rock Resource. The hot rock-type of resource requires a different approach. In this type of resource, the heat is contained in huge blocks of impermeable rocks in which water cannot accumulate.

The rocks lying near the surface of the earth can be reached by conventional drilling equipment and methods. It may prove feasible in some regions to drill pairs of holes in such rock and to create interconnecting fractures by injecting water under great pressure. As the water flows through the hot rocks, it would be heated. It would then be withdrawn through another well.

Depending upon conditions, the injected water could convert the hot rock-type resource into either a vapor-dominated or hot water-dominated resource. It could then be handled by one of the methods described earlier.

The feasibility of extracting energy from hot dry rock is currently being investigated in north-central New Mexico under a program sponsored by the Atomic Energy Commission.

IV. WHAT ARE THE PROBLEMS INVOLVED?

As with the development of any new industry, the extraction and conversion of geothermal resources have presented a multitude of problems. Some have been solved, others are under study, and still others are yet to be clearly defined.

Technical Problems

The first technical problem centers around the questions: Where are the geothermal resources? In what quantity and quality do they exist? And what is their heat content? As has been indicated, we know in general where many of the reservoirs are, but before commercial development can be undertaken, a knowledge of exact locations and reliable estimates of quantity, quality, and heat content are necessary.

Exploration to answer these questions can be done by either indirect or direct methods. Indirect methods, such as seismic, magnetic, electric, gravimetric, and geochemical surveys, can yield information on depths to bedrock, types of formations, boundaries of formations, and locations of water-bearing formations. They are relatively inexpensive and are definite aids in selecting sites for test holes. But by themselves, indirect methods rarely give enough information to enable a developer to pinpoint and evaluate the geothermal resources within the reservoir. For this information, he must go to the more costly direct methods--drilling test holes and pilot wells.

For extraction of geothermal fluids, techniques developed by the oil industry can be applied; however, some problems are unique to the geothermal resource. For one thing, geothermal fluid and steam are often mineralized. Therefore, they are corrosive and they tend to deposit minerals on the piping and mechanical equipment. Turbine blades, in particular, are vulnerable to corrosion and erosion from rock particles, minerals, and other debris that may get into the mechanism. Providing special finishes on equipment and special handling will increase the cost of production.

In the Imperial Valley, geothermal brines contain large quantities of silica, which precipitates out of solution when the brines are cooled, forming scale in the wells, pipelines, and other equipment. Therefore, alloys, vessels, and procedures must be found to cope specifically with problems of silica coating. Technology devised for these will, in large measure, determine the amount of maintenance required and the frequency with which facilities must be replaced. Consequently, there is an immediate need for advancing the technology of coping with such brine.

The high concentration of minerals in the resource also increases the problem of disposing of waste. Unless the waste brine is properly disposed of, it can increase the salinity of the local water supply, decrease the amount of arable land, and threaten the maintenance of wildlife habitats.

Although the steam from a vapor-dominated resource generally condenses to a small volume of water with only traces of dissolved constituents in it, some of the trace elements, such as boron, can be toxic to animals and plants if the water is discharged on the surface. The disposal method used at The Geysers geothermal field is

Crust of minerals deposited on brine line at Cerro Prieto plant.

injection of the condensate through special wells into the ground.

A water-dominated resource, such as that in the Imperial Valley, would require many more wells for injection because of the large volumes of water extracted. Also, water-dominated resources generally contain higher concentrations of minerals than do vapor dominated.

The California Regional Water Quality Control Board, Colorado River Basin Region, has played an active role in controlling the disposal of geothermal brines to surface and ground water in the Imperial Valley. Discharge of geothermal wastes into any conveyance that leads into the Salton Sea has been effectively prohibited.

Possible disposal of brine waste to the Pacific Ocean would require the construction of an extensive and costly conveyance system because of the need to transport the waste from below sea level in the valley, over the mountains, and to the ocean. The route to the Gulf of California crosses no mountains, but international agreements with Mexico would be required before this could be undertaken. The use of ponds from which the liquid could evaporate has been considered for disposing of the waste, but the ponds would require large tracts of land and would leave a residue, which would later have to be disposed of in some manner. Therefore, the use of injection wells in Imperial Valley is being studied as the most promising method.

Environmental Problems

Many of the technical problems are also environmental problems. To illustrate,

unless geothermal wastes are properly handled and disposed of, the environment will suffer.

According to both federal and state law, before development such as that required for extracting geothermal resources can be undertaken, studies must be made of the possible impact upon the environment, and reports must be prepared on the findings.

Environmental impact reports are designed to inform and disclose to the public and the decision makers the environmental effects of a proposed action.

From the standpoint of environmental effects, the development and production of the geothermal resource can be divided into a number of distinct phases, such as exploration; test drilling; production testing; field development; power plant, power line, and pipeline construction; and full scale production. Each phase will have some specific effects upon the environment.

Because it is unlikely that all impacts of a particular geothermal project can be anticipated, monitoring of effects both before and during development and throughout operation of the completed project should be undertaken to detect any unexpected significant consequences.

Drilling and operation of wells could create noise and dust and could release gases such as hydrogen sulfide, carbon dioxide, and ammonia to the air.

Certainly, access roads would have to be built, buildings constructed, electrical transmission facilities installed, and power plants, pipelines, and perhaps desalting plants erected. These facilities would generally alter the existing use of the land.

Also to be considered is the possibility that the removal of large quantities of geothermal resources could result in change to the structure of the land, such as subsidence and earth tremors or other seismic activities. Injection of waste brines also could cause seismic activity.

Subsidence has resulted from extraction of fluids from the ground at oil fields in many parts of the world. The geothermal fields at Wairakei, New Zealand, and Cerro Prieto, Mexico, have also reported subsidence, although no correlation between the land subsidence and withdrawal of geothermal resources at Cerro Prieto has been established.

The rate and extent of subsidence in different areas vary widely, and no reliable predictions can be made for a specific area until it has been thoroughly explored. This is because subsidence is determined by such factors as the geologic structure of the underground reservoir, the nature of the sediments containing the fluid, and the change in pressure within the sediments that takes place as the fluid is withdrawn and is injected. Areas also vary in the amount of subsidence that can be tolerated. For example, on undeveloped desert land, subsidence of several feet might be acceptable. But on the irrigated land of the Imperial Valley, subsidence of only a few inches could cause extensive damage to the expensive irrigation and drainage systems.

Injection of water to replace the withdrawn fluid has been successful in minimizing the subsidence at a number of oil fields. One at which it has reduced the rate of subsidence is the Wilmington Oil Field in the harbor area of Los Angeles and Long Beach.

Legal and Institutional Problems

A study made in 1971 by the University of California concluded that legal and institutional problems ranked a close second to brine chemistry problems as significant deterrents to the development of the geothermal resource.

HOW HOT MUST GEOTHERMAL LIQUID BE?

As a rule of thumb, the temperature of geothermal liquid must be at least 350° F. (180° C.) for the production of electric power to be considered economically feasible under present technology, according to Donald E. White of the U. S. Geological Survey.

However, heat is important only as it contributes to the production of steam, which is the force that drives electric generators in today's power plants.

Unless the flow of geothermal liquid can be sustained at a sufficiently high level to ensure a large and steady supply of steam, operation of a well will not be practical even though the temperature is high.

The legal and institutional problems tend to fall into three major groups:

1. Ownership problems;

2. Regulatory and jursidictional problems; and

3. Marketing problems.

The following is a summary of the detailed discussion that is included in Appendix A.

Ownership Problems. Unlike oil and natural gas, which carry stored energy that is later released by burning, geothermal fluids carry energy that requires no combustion. Further, the resource is multipurpose: its products may be not only electrical energy, but also fresh water, minerals, and space heating. Thus, neither the legal regime surrounding the ownership and and administration of minerals nor that which pertains to water seems entirely applicable to the geothermal resource.

As a first step toward solving the ownership problems, the Federal Government has begun legal action to determine (1) if the courts regard the geothermal resource as a mineral, and (2) if so, do they consider it one of the minerals to which the government has retained rights under its various land grants. The state government has begun similar legal action regarding ownership of geothermal resources on state lands.

If the geothermal resource is held to be water, this too will pose problems. For one thing, will it then be subject to state water laws, as is nongeothermal water? And, if the owners of the surface rights and mineral rights are not the same, who will own the minerals produced in connection with the geothermal fluid?

Regulatory and Jurisdictional Problems. Any body of regulations that covers all aspects of this multipurpose resource must have the flexibility to accommodate varying market conditions and needs. To illustrate: The steam or hot water extracted from a geothermal resource must be used near the source of heat. The electric energy produced most likely would enter the established power distribution grids of a utility. In this respect, the market is a controlled one. On the other hand, the mineral products of the geothermal resource could enter an open market, and they would not face the same need for immediate use. Further, fresh water produced from the resource would have its own marketing and distribution arrangements.

As a mechanism for permitting geothermal exploration and for protecting against immediate environmental damage, the regulations developed by the Federal Government, the state government, and the local government (as in Imperial County) appear adequate. However, these regulations must also permit a delicate balance between encouraging investment of private capital to assume exploration risks, on the one hand, and, on the other, planning and coordinating to integrate geothermal resource development into California's complex power and water generation and consumption patterns.

Also, the body of regulations for managing development must be able to bring together the various political entities involved in specific domains or reservoirs. Geothermal resources, similar to oil resources, are likely to be defined in terms of reservoirs.

These reservoirs, however, could underlie a combination of federal, state, county, and private lands. Under such circumstances, who will be responsible for the management of a single geothermal reservoir? Although the basic framework for each regulatory level has been set up, the machinery is lacking to accomplish coordinated planning and regulation on a team basis.

Marketing Problems. Although the technology and physical characteristics require that assessment and development of the resource be integrated with generation of power, this integration has been hindered because the resource development industries and the utilities have completely different financial policies and regulations. The development of geothermal resources involves expensive and risky drilling. Electric utilities are understandably reluctant to underwrite risky exploration.

A second obstacle to more rapid development of geothermal resources is the long unproductive periods between exploration and establishment of the geothermal reservoir to produce power. Utilities need some assurance of the quantity and life expectancy of a reservoir before they commit themselves to construct generation and transmission facilities. Thus, the developer will need to spend substantial capital in proving the capacity of the total field. Unlike oil or hard minerals, the discovery of steam or hot water in one well does not guarantee that the resource is marketable.

A third deterrent to more rapid development is the realization that geothermal development is especially susceptible to antitrust scrutiny. First, power will be produced in large measure by publicly-owned and privately-owned electric utilitie which, under our legal system, are granted special privileges, encouraging exclusive distribution systems. Second, geothermal resources are geographically restricted to their source for energy production. Third, the suppliers of geothermal steam or water are likely to be oil companies with substantial land or mineral ownership in a given geothermal reservoir area. And finally, the market for electricity is more closely regulated than is the market for fossil fuels.

Some of the extensive pipelines used to transport steam from the geothermal wells to the electrical generating plants at The Geysers.

--Pacific Gas and Electric Company photo

V. WHAT OF THE FUTURE?

Predicting the future of geothermal resources development is as risky as is forecasting in any other field. Nonetheless, a number of possible markets for the products from these resources appear fairly certain, provided the various problems that have been pointed out can be solved.

Given below are, first, an outline of possible markets and, second, a listing of some of the studies needed to supply the information and techniques required for solving the problems that have been posed.

Possible Markets

In addition to the obvious possiblities of using the geothermal resource for generating electrical power, for producing fresh water, and for extracting minerals, development in the Imperial Valley also offers a possible solution to the problem of the increasing salinity in the Salton Sea.

The sea is one of the most heavily used bodies of water in the State. Estimated use rate is 1.5 million recreation days annually, and public and private investments in recreational facilities total more than $900 million. Because the increasing salinity of the water in the sea is threatening the important fishery, federal and state agencies have conducted a cooperative study to develop and recommend measures for checking the trend.

Among the measures under considereation is one to pump out some of the saline water and dispose of it to dry lakes where it could evaporate. Some of the saline water pumped out of the sea might be injected into the ground to replace those geothermal brines that are removed. This could both help dispose of some of the saline water from the Salton Sea and help minimize possible land subsidence from removal of geothermal resources.

Conversion to Electrical Energy. The greatest interest in geothermal resources is as a source of energy. At a number of places in the world, including The Geysers in Northern California, this conversion is now taking place on a commercial scale. In the Cerro Prieto geothermal field, south of the Imperial Valley, the Mexican government began operation of an electrical generating station in April 1973.

The resource in the Imperial Valley, although estimated to be even larger than that at The Geysers, is not as readily convertible to electrical energy. The resource at The Geysers is predominately in the form of steam; that in Imperial Valley is predominately hot brine. Nonetheless, estimates of the potential in the Imperial Valley that have been made by investigators from the University of California at Riverside run as high as 20 million kilowatts. Other investigators have indicated they feel that the potential is not that large, but that the resource is of significant proportions.

Readily available markets for the power produced in the Imperial Valley lie in the population and industry of the coastal zone of Southern California and in the energy needs of the State Water Project--if the cost can be competitive with that from other sources.

The State Water Project is both a producer and a user of electrical energy. To meet a portion of the pumping demand during the on-peak periods, electrical energy has been imported from the Pacific Northwest.

When water deliveries were small (1968 through 1973), a surplus of approximately 17.3 billion kilowatthours of electrical energy was produced by the project for sale to utilities in the State. Between 1973 and 1976, the power demand and supply will be about equal. But, as water deliveries increase beyond 1976, the demand will exceed the project supply.

For this reason, the Department of Water Resources, constructor and operator of the project, has maintained a continuing program to develop dependable sources of supplemental power.

Geothermal is among the potential sources of energy being investigated under this program.

Water Supply by Desalting Geothermal Brines. Interest in the possible desalting of geothermal brines is largely centered on the resource in the Imperial Valley because of the high water content of the resource and the proximity of markets. Investigators have estimated that it may be feasible to develop a production of a significant amount of distilled water each year from the vast reservoir in the valley. As has been pointed out, the rich agricultural production of the Imperial Valley depends upon year-round irrigation from the Colorado River. But the river water has become increasingly mineralized and the water supply is fully committed to supply rights that have been established. Thus, fresh water obtained by desalination of geothermal brines would be welcome if the cost of such desalination can be competitive; so far it is not.

The fresh water could be either (1) added directly to the Colorado River, (2) used as a direct supplemental water supply to meet municipal and industrial purposes in the Imperial valley, or (3) blended with Colorado River water in the All-American Canal, which serves the Imperial Valley agriculture.

Extraction of Minerals. Of the three major products from geothermal resources, the extraction of minerals for marketing appears the least promising at this time. At both the Larderello geothermal field in Italy and the Imperial Valley field in Southern California, extraction and marketing of minerals and chemicals have been tried, but at this time, they are not competitive with those from other sources.

However, some geothermal resources (particularly those around the Salton Sea) have mineral constituents, such as lithium, silver, and gold, that are commercially valuable. Recovery of certain minerals may again prove feasible in time, depending upon the comparative cost and availability of the minerals from other sources.

Studies Needed

Both public and private interests have recognized the potential that lies in the geothermal resource, and they have been willing to invest time, money, and skill in finding ways to develop the resource.

To supply the information and techniques needed for solving some of the problems

HOW MUCH ELECTRICITY

The generating capacity of The Geysers is 396,000 kilowatts of electrical power. For comparison, the electrical power requirements of a city the size of San Francisco are about 600,000 kilowatts.

For further comparison, Oroville Dam of the State Water Project has an installed capacity of 679,000 kilowatts, the capability of Hoover Dam is rated at 1,423,000 kilowatts, and the total capacity (August 1974) of the San Onofre Nuclear Generating Station (owned and operated by Southern California Edison Company and San Diego Gas and Electric Company) is 450,000 kilowatts.

they face, a number of studies and surveys will be required.

A list of specific studies needed would include the following (this does not imply that all would be needed at every potential geothermal field):

1. Exploratory studies to supply the data needed to help in the determination of the physical characteristics of geothermal reservoirs.

Even in the Imperial Valley, where exploration has been going on for a number of years, the necessary geologic and hydrologic data are lacking on which to base accurate estimates of the quantity and quality of the resource. Not enough is known about the size and depth of the reservoir, its storage and transmissive characteristics, and the variation in quality of brines found at different locations and depths. Also, more information is needed on subsurface temperatures throughout the valley so that other possible geothermal anomalies can be pinpointed.

2. Evaluation of Obtaining Fresh Water from Geothermal Brines.

The suggestion has been made that water distilled from geothermal brines could be blended with the increasingly mineralized water from the Colorado River to extend the usefulness of local water resources.

However, research to date indicates that the cost of desalting the brines will be high.

To be able to assess the possible role of geothermal resources in providing a water supply, a number of problems will require study as mentioned in the following sections of this report.

Unless solutions that are practical and economical can be found to these problems, the high cost of desalting will limit the use of geothermal resources to produce fresh water.

3. Surveys of geothermal fields to help prevent possible land subsidence and seismic activities.

In the Imperial Valley, federal, state, and local agencies conducted a survey of ground elevations in 1971 and established bench marks across the valley to provide the basic data for monitoring earth movements. A continuing surveillance program is planned so that changes in elevation can be detected as they take place.

In addition, the U. S. Geological Survey has added 16 stations for monitoring possible seismic activity in the valley. Similar surveys might be needed at other geothermal fields.

4. Some of the applied research projects that would be needed would develop:

- Solutions to problems of corrosion, scaling (especially silica scaling), and abrasion caused by saline brines and steam;

NEW FEDERAL LEGISLATION

In support of the U. S. program to develop self-sufficiency in energy (known as Project Independence), the Geothermal Energy Research, Development, and Demonstration Act of 1974 was enacted.

The stated purpose of the act is: "To further the conduct of research, development, and demonstrations in geothermal energy technologies, to establish a Geothermal Energy Coordination and Management Project, to provide for the carrying out of research and development in geothermal energy technology, to carry out a program of demonstrations in technologies for the utilization of geothermal resources, to establish a loan guaranty program for the financing of geothermal energy development, and for other purposes."

Rig used for geothermal drilling on south shore of Mono Lake. In front of the drilling rig are towers of tufa, which is a porous rock formed by evaporation of waters that are high in calcium. The hill in the background is an extinct volcano.

- o Methods for disposing of waste brine that are both environmentally and economically acceptable, and

- o Facilities for the combined economical production of power, fresh water, and minerals.

Studies directed toward the first two of these problems have begun in the Imperial Valley. Leading the search for ways to handle the problems of corrosion and scaling are the U. S. Office of Water Research and Technology and several of the developers, including Magma Power Company, San Diego Gas and Electric Company, and Union Oil Company. Methods for disposing of waste brines are being tested by the U. S. Bureau of Reclamation, Imperial Thermal Products, Southern California Edison Company, Southern Pacific Land Company, Phillips Petroleum Company, and GEMCOR, among others.

5. Studies for the development of practical and effective environmental protection plans for the areas where geothermal resources are found.

The needed studies would include the determination of present conditions in the area and the evaluation of the direct and indirect environmental impact expected from exploration and production plus the development of means to avoid or mitigate the adverse effects. At the same time, those aspects, such as provision of water or power, that are seen as a means of improving the environment could be given priority.

Both the National Environmental Policy Act and the California Environmental Quality Act provide guidelines and requirements regarding environmental protection from any proposed project. Local areas are also establishing guidelines in fulfillment of the California law. These should provide a framework for the environmental plan.

6. Fact-finding studies by legislative committees and State and Federal agencies pointing to the solution of some of the legal and institutional problems that may hinder development of geothermal resources.

For one thing, sound legislation may be required to help resolve some of the complex ownership problems. Extensive

Interior of one of the power generating plants at The Geysers. Although the source of the steam is the geothermal resource, the turbine generator units are the conventional type.
California Division of Oil and Gas photo

fact-finding studies would be needed to supply the information on which such legislation could be based.

To guide them in their future course of action in regard to the geothermal resource, legislators and other decision makers will have a continuing need for developments--both private and public--to be monitored, evaluated, and reported.

Consideration may also need to be given to a functional management scheme that would satisfy the needs of federal, state, and local governments to exercise control over their respective lands and interests, yet not force one to yield its jurisdiction to the other. Such a partnership now exists for water development through such federal-state institutions as the river basin commissions. A study to determine if some management control devices along these lines can be established would appear warranted. Such a mechanism might also facilitate the incorporation of the multipurpose applications of the basic resource.

The legislative bodies may wish to encourage geothermal exploration and development through a depletion allowance or some other device. At present, the extension of depletion allowances to the geothermal resource rests upon a single court decision, which may or may not be extended to the resource when found under different conditions. In addition, present laws do not require that the resultant tax savings from depletion allowances be reinvested in exploration and development to ensure a continuing supply of the resource being depleted.

Both direct and indirect financial assistance may be advisable for private and public entities in their explorations, especially when no immediate market for the resource is available or feasible. When all the various factors that influence the market for a resource are considered, government entities may find that their best long term interest would be to conduct some of the exploration themselves to encourage subsequent private development.

Fact-finding studies are needed to supply the information on which such a decision would be based.

In some of the KGRA in California where exploration has been limited, reconnaissance-level investigations are needed to identify potential production areas.

The California Legislature may also wish to study the factors that raise the specter of antitrust actions against developers of the geothermal resource and to determine if steps can and should be taken to ensure that this infant industry is not unduly hampered by artificial development or market restraints.

Appendix A

LEGAL AND INSTITUTIONAL PROBLEMS

Appendix A

LEGAL AND INSTITUTIONAL PROBLEMS

In part, many of the doubts about the viability of geothermal energy as a significant contributor to our energy supplies within the next ten years are caused by unresolved legal and institutional problems associated with the geothermal industry. This outlook is substantiated in a 1971 University of California study, "Ranking Research Problems in Geothermal Development", which concluded that the first research priority is brine chemistry, but that the legal and institutional problems rank a close second in a field of eight subject areas.

The fundamental legal inquiries associated with geothermal resources can be divided into three major headings:

1. Ownership of resource: controversy between mineral estate and surface estate interests;
2. Regulatory and jurisdictional problems; and
3. Marketing problems.

Ownership Problems

Unlike oil and natural gas which carry stored energy released by subsequent combustion, geothermal fluids bear their energy without combustion. For this reason, geothermal resources constitute an indigenous source of energy. From an environmental and economic viewpoint, this basic characteristic of the resource constitutes one of its key attributes. From a legal viewpoint, however, the elusive components of the resource make it clear that neither the existing legal regime surrounding the ownership and administration of minerals or that concerned with water may in and of itself be adequate.

Although electric energy production appears to be the most important product of geothermal resources, the resource is basically multipurpose and may also include fresh water production, mineral production, and space heating, even hothouse and hydroponic agriculture. The diverse number of geothermal systems and processes make it impossible to describe the resource generically. Some geothermal systems may utilize the heat from hot rocks below the surface, while others may bring heat to the surface in the form of steam or water, perhaps even in combination with combustible gases. It is therefore necessary to conceptualize geothermal resources in broader terms than the traditionally known geyser, or fumarole, phenomenon.

The search for a proper legal regime should <u>not</u> center around the question of whether the resource is a mineral or water, but rather should carefully evaluate the consequences that accompany each such categorization. A categorization for purposes of determining ownership may prove not to be the most desirable and appropriate for management and development.

Because of uncertainty over whether or not various mineral reservations encompassed geothermal resources, Congress, in the Geothermal Steam Act of 1970, required the U. S. Attorney General to institute proceedings to quiet title in the United States. U. S. v. Union Oil Company of California was the first such case filed in the U. S. District Court in San Francisco. In October of 1973, the judge granted a motion for summary judgment in favor of the defendants. In his decision he concluded that the meaning and scope of the mineral reservation in the Stock Raising Homestead Act of 1916 did not include geothermal resources. This decision has been appealed, and a final determination will probably need to await action by the U. S. Supreme Court.

If geothermal resources are considered to be water, there remains the question of whether or not water associated with heat is subject to the regulations and control of the states under their applicable water laws. The applicability of state water laws is especially relevant if geothermal waters have some connection with the usable ground waters, a controversy which has not yet been resolved.

The Geothermal Steam Act of 1970 (84 Stat. 1573, 30 U.S.C. 1001-1025) leaves unresolved the question of whether or not geothermal steam and associated geothermal resources are to be regarded as part of the water resources of a state and therefore are subject to applicable state water laws. California Public Resources Code Section 3742.2 attempts to resolve this difficulty with respect to federal, state, and private lands through the granting of a certificate of primary purpose by the California Geothermal Resources Board. If the board determines that a well is drilled primarily to produce geothermal resources, it may issue a certificate of primary purpose. This certificate would establish a rebuttable presumption that the lessee has absolute title to the geothermal resources reduced to his possession from such a well. Other persons may rebut this presumption only by showing that the water content of the well is useful for irrigation or domestic purposes without treatment and that it is not merely a byproduct of the geothermal resources. The certificate of primary purpose may thus serve as a mechanism to determine under which circumstances geothermal waters may or may not be subject to conventional water law. It should be noted, however, that up to this point no such certificates of primary purpose have been issued by the Geothermal Resources Board nor have any applications for certificates been filed. The viability of these certificates may also be thrown into doubt by future judicial classifications of the geothermal resources as water.

Like the Federal Government, the State of California also faces an ownership dispute with respect to geothermal resources on state lands. In 1973 the case of Pariani v. State of California was filed to determine ownership of the geothermal resource in The Geysers area. The California trial court has denied the plaintiff's motion for summary judgment, unlike the federal court in the U. S. v. Union Oil Co. case. Therefore, this state court case will go to trial on the question of whether or not the State's mineral reservations cover geothermal resources. The California Attorney General has indicated the intention to file a brief in support of the appeal in the federal court.

A question that will also need to be addressed is: Who owns the minerals produced in association with, and extracted from, geothermal fluid if it is determined that geothermal resources are not mineral and there has been a severance of the surface and mineral estate? When the owner of the minerals and owner of the surface are one and the same, no particlar problem exists. But when the owners are different, the matter becomes complex. The final answer will come only with judicial determination or perhaps prospectively with legislation. Until this point is reached, prospective developers will need to cover the respective rights of all parties in lease agreements.

Tax Problems

The classification of geothermal resources (mineral, water, sui generis, or heat) will affect their treatment for tax purposes. Federal tax law does not provide a depletion allowance specifically for geothermal energy. However, in 1969, the tax court held in Reich v. Commissioner of IRS, 52 T.C. 700 (1969) that the natural steam at The Geysers qualified for a depletion allowance. The producers were also entitled to write off as expenses the intangible costs of drilling and developing The Geysers field.

In this case, the tax court held that the geothermal steam in question is not ordinary ground steam that is fed by constant water seepage, which would make it inexhaustible. Rather, the judges reasoned, it is locked in closed spaces like natural gas and is not replenished by seepage. It was therefore held to be depletable and subject to the same tax treatment as natural gas with respect to depletion allowance and intangible drilling and development costs.

A depletion allowance can serve to foster discovery and development of indigenous resources. This encouragement of geothermal resources may be desirable, whether accomplished by depletion allowance or by some other means. Under present laws, however, there is nothing to require that the resultant tax savings be reinvested in exploration and development to ensure a continuing supply of the resource being depleted.

The logic of the Reich case may not be extended to depleting hot water and hot rocks reservoirs. Future court challenges to the depletion allowance for geothermal resources appear certain.

Regulatory Problems

Perhaps because of the similarities of the technologies utilized to extract the resources, many legal aspects of the geothermal resources field have been compared with the legal regime of the petroleum industry. Although there are substantial similarities, the distinctions become especially apparent when the modes of utilization and market conditions are considered.

Steam or hot water extracted from a geothermal reservoir, because it can neither be transported long distances nor stored for long periods, must be utilized in the immediate vicinity of the source of heat. The product of electric energy must be either sold to a large consumer or enter the established distribution grids of publicly-owned or privately-owned utilities. It is this necessity for immediate utilization in interconnecting grids that makes geothermal power similar to hydropower. From this point of view, the geothermal power production industry of necessity differs from the more complex mechanisms of the petroleum industry where the energy commodity is removed from its source to be transported, refined, and sold on an open market. In conceptualizing geothermal power, planners, developers, and legislators must therefore take into account the special problems created by a controlled market, which may need to reflect such noneconomic factors as the long and short term needs and conveniences of the public.

On the other hand, if the geothermal resource is utilized for the production of minerals, the commodity produced can enter an open market and does not face the same need for immediate utilization.

Finally, if fresh water is produced from the resource, consideration must be given to the market and distribution of this resource as well.

It is therefore necessary that any legal or regulatory regime which covers all aspects of this multipurpose resource have the flexibility to accommodate varying market conditions and needs.

Thus far, most of the geothermal exploration in the United States and California has been conducted on private lands. This fact is attibutable partly to the initiative taken by private industry and partly to the fact that federal lands have only recently been made available to private industry for exploration and development. Many of the more promising geothermal areas in the western states are situated on federal lands.

1. Federal

In 1971, 1.8 million acres (7,300 square kilometers) of federal and non-federal land was classified as being within Known Geothermal Resource Areas (Federal KGRA) by the U. S. Geological Survey, with another 96 million acres (390,000 square kilometers) designated as having potential geothermal resource value. California has within its borders more than 1 million acres (4,000 square kilometers) of the designated Federal KGRA. To encourage and facilitate development of these geothermal resources on federal lands, Congress passed the Geothermal Steam Act of 1970 (84 Stat. 1566). Regulations required to implement this act have now been adopted for four categories: exploration, leasing, operations, and unitization (pooling of leases). Although the regulations cover independent actions, with the Bureau of Land Management supervising the exploration and leasing functions and the U. S. Geological Survey supervising the operations and unitization functions, the individual regulations overlap and in fact must conform to other regulations that apply to geothermal development in general, such as special land use permits and protection of the surface and other mineral resource development. Working under these regulations

is further complicated by the fact that many other agencies of the Federal and State Governments, such as the Office of Management and Budget, the Agriculture Department, and many state agencies are involved.

Leases under the Geothermal Steam Act of 1970 would be granted on both competitive and noncompetitive bases to qualified individuals, associations, corporations, or governmental units for an initial term of 10 years. If geothermal steam is produced or utilized in commercial quantities within this initial, or primary, term of a lease, the lease will be continued for up to 40 years after the end of the primary term. Lands within a KGRA are leased to qualified bidders by competitive bidding, while lands outside a KGRA may be leased without such competitive bidding. Based on the productivity of the leased acreage, royalty payments range between 10 and 15 percent of the amount, or value, of steam or of any other form of heat or energy derived from production under the lease.

Under such leases, it is contemplated that state laws will govern the development of any natural potable water that may be developed. State laws will also probably govern the uses to which commercially demineralized water can be put, unless Congress specifically addresses this question in future legislation. Under the present legislations, the Secretary of the Interior may under warranted circumstances require the production and use of usable water by the lessee. Such use or production of water will be conducted in accordance with state water laws (43 CFR 3242.1), as long as it does not result in undue waste of geothermal energy (43 CFR 3242.2-2).

In the area of environmental controls, the federal leasing regulations require the lessee to comply with all federal and state standards and all applicable local standards. In addition, the supervisor may, at his discretion, establish additional and more stringent standards (30 CFR 270.41). A lessee is also required to take specific actions on the following:

1. Comply with the rules of the Department of the Interior and Environmental Protection Agency for the use of poisonous substances on public lands (43 CFR 3204.1(c)(1)).

2. Conduct lease operations in accordance with state water quality standards and public health and safety standards and applicable local water quality standards, and toxic materials shall not be injected into surface or ground waters (43 CFR 204.1(c)(2)).

3. Control emissions from operations in accordance with federal and state air quality standards and applicable local air quality standards (43 CFR 3204.1 (c)(3)).

4. Employ soil and resource conservation and protection measures on the leased lands (43 CFR 3204.1(c)(4)).

5. Control noise emissions from operation in accordance with federal noise emission standards and applicable local noise emission standards (43 CFR 3204.1 (c)(5)).

6. Remove or dispose of waste material in accordance with its approved plan of operation (43 CFR 3204.1(d)).

7. Take precautions to minimize land subsidence and to monitor operations for land subsidence and for seismic activity (43 CFR 3204.1(e)).

8. Consider aesthetics in the design and construction of facilities (43 CFR 3204.1(f)).

9. Protect fish and wildlife and their habitat (43 CFR 3204.1(g)).

10. Conduct activities on antiquities and historical sites in accordance with lease terms (43 CFR 3204.1(h)).

Finally, before commencing any operations on the leased land, each operator must submit comprehensive development plans and environmental protection measures for approval by the supervisor (30 CFR 270.30, 220.74, 270.76, 270.77).

Although the first leases have only recently been let under these regulations, the framework for a manageable system of development on federal lands appears to have been created, and actual experience in the next few years should produce any needed adjustments and corrections. However, where state and privately owned lands are intermixed with federal lands, considerable cooperation will be required to achieve orderly and economical development in view of the numerous laws and regulations applicable.

2. <u>State</u>

The State of California passed its laws for the conservation of geothermal resources in September of 1965 to regulate drilling and abandonment activities (Chapter 4, commencing with Section 3700, Division 3, Public Resources Code). This law came into being five years after the first geothermal power plant began production and more than 10 years after the start of serious geothermal exploration.

Under the provisions of this law, the Division of Oil and Gas and its supervisor are granted regulatory jurisdiction over the drilling, maintenance, and abandonment of all geothermal wells, including any reinjection wells drilled in the State. The law provides for the filing of notices to drill, rework, or abandon wells; production records; logs and histories; and other information deemed necessary by the supervisor. The California statutes provide for "permissive" unitization of individual geothermal resource activities on the same reservoir.

The Geothermal Resources Act of 1967, enacted by the California Legislature, established a basic framework within which the State Lands Commission may lease state-owned lands for purposes of geothermal exploration and development. The commission may issue permits and leases on all lands owned by the State. In the case of lands where the surface is under the jurisdiction of a state department or agency other than the commission, such permit or lease must be obtained with the consent of the

other department. Exploration permits may be issued for prospecting on lands not known to contain geothermal resources. Upon classification of an area as a geothermal resource area by the commission (acting either independently or upon the advice of the Geothermal Resources Board), procedures are provided for preferential and competitive bid-leasing.

The Geothermal Resources Act of 1967 also established the Geothermal Resources Board, which is composed of seven officers designated by statute: the director of the Department of Conservation, the state geologist, the director of the Department of Water Resources, the executive officer of the State Lands Commission, the State Oil and Gas supervisor, the chairman of the State Water Resources Control Board, and the chairman of the Public Utilities Commission. This board serves as an advisory body for development of the resources and as a board of appeal from regulatory requirements. It also makes recommendations as to the classification of State Known Geothermal Resources Areas (State KGRA) and Geothermal Resources Areas (GRA). To assist the board in performing these functions a Technical Advisory Committee has been formed which, unlike the board, meets on a regular basis.

As was indicated earlier, the Federal Government has created KGRAs to achieve a basis for its leasing and operating regulations. On the state level, the State Lands Commission also utilizes the KGRA concept; however, there is a major difference. The State KGRA must contain a well capable of producing geothermal resources in commercially usable quantities before the area can be classified as a KGRA. This stricter classification requirement may merit further legislative consideration as geothermal development accelerates. At present, an interested individual or entity may apply for an exploration permit for state lands that are surrounded by proved and established geothermal wells, a factor which substantially reduces the risks in locating the resource. After a producing well has been drilled under the permit, the area will be classified as a State KGRA, and competitive bidding for leases will be required. However, the exploration permit holder becomes entitled to a preferential lease through his initial permit. As certain areas become established geothermal reservoirs, the requirement that adjoining state lands contain a producing well capable of commercial utilization may prove a windfall to exploration permit holders and an economic loss to the State. A related question that will also need clarification is whether or not the establishing of one geothermal well by the permit holder in a parcel qualifies the entire permit area for such a preferential lease.*

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* A bill introduced in 1974 by Senator Dills, SB 2092, could remedy many of the problems cited above. The 1974 Legislature referred the bill for study by the Senate Committee on Geothermal Resources.

The bill would make several significant changes in the Public Resources Code. Its most important provisions are these:

1. It increases membership on the Geothermal Resources Board to include two officials from a county or counties where geothermal resources are being produced.
2. It deletes provisions authorizing the issuance of "prospecting permits" and instead authorizes only the restricted issuance of permits for "geological or geophysical surveys".
3. It eliminates the concept of preferential rights to geothermal resources permits or leases and all reference to provisions for classification of lands as "known geothermal resource areas" (KGRAs).
4. It provides for bid leasing of State lands for geothermal resources and allows the State to negotiate royalty rates in excess of 10 percent.

The Division of Oil and Gas is now in the process of delineating "Geothermal Resources Areas" (GRA) throughout the State. Although these GRAs will have geographic proximity to the Federal and State KGRAs, they are distinct areas designated for regulatory purposes only, as opposed to leasing activities. Any wells drilled within such GRAs will become subject to geothermal regulatory laws, with exceptions specified by regulations adopted by the Division of Oil and Gas.

As can be seen, three different geothermal areas exist in the State of California: the Federal KGRA, the State KGRA, and the State GRA. As the pace of development quickens, some coordination in the designation and administration of these three regulatory territories will become essential.

Under the Federal Water Pollution Control Act as amended (33 U.S.C. 1151, et seq.), the primary responsibility for water pollution control on the intrastate level is assigned to the state. In California, the statewide responsibility for these standards rests with the State Water Resources Control Board. Regional water quality control boards carry out the functions delegated to them under applicable federal and state laws. Each regional board is responsible for the preparation of a water quality control plan that sets forth policy guidelines, water quality objectives, discharge prohibitions, and implementation and surveillance programs. With respect to geothermal operations, each operation is considered by the appropriate regional board, and orders are issued setting forth waste discharge requirements for the specific operations. Examples of these and other federal and state environmental requirements are set forth in the environmental impact statement prepared for the federal geothermal leasing programs.

In addition to the State Water Resources Control Board, the Department of Fish and Game, Air Resources Board, and Division of Forestry also exercise limited regulatory authority in the development of geothermal resources, when such development impacts upon resources under their jurisdiction.

In May of 1974 the California Legislature enacted the Warren-Alquist State Energy Resources Conservation and Development Act (Stats. 1974, Chap. 276) to become operative January 7, 1975. This act establishes the State Energy Resources Conservation and Development Commission, which will certify power plant sites and facilities, including geothermal facilities. In view of the need to locate geothermal power plants at the site of the geothermal reservoir, the power plant siting certificate requirements are reduced to accommodate the needs of this industry.

New Section 25600 of the act also assigns to the commission the responsibility to develop and coordinate a program of research and development for geothermal resources. The role to be played by the State in the exploration and accelerated development of geothermal resources remains for determination by the commission in 1975.

The Department of Water Resources does not exercise any regulatory jurisdiction over geothermal resources. However, because of the potential for developing fresh water supplies, and because of the need for electrical power for the State Water Project, the Department conducts investigations of geothermal resources.

3. County

In many respects, the county will be the most directly affected governmental entity with the coming of the geothermal era. From the standpoint of available resources to cope with the onslaught of major changes to their present land use, industry, and social patterns, counties such as Imperial will need substantial assistance from the State and Federal Government to achieve planned progress.

With assistance from the Division of Oil and Gas, the County of Imperial has drawn up and adopted a set of interim regulations until a countywide geothermal plan can be adopted. These regulations spell out terms, conditions, and applications procedures for initial private geothermal development in the Imperial Valley. Although these regulations constitute a step in the right direction, the development of an overall plan may be expedited to avoid piecemeal planning.

Geothermal resources must be utilized in proximity to their discovery. This requires that some planning take place prior to the exploratory or assessment phase of development by the local entity.

Traditionally, the courts have upheld a fairly broad zoning, planning, and environmental protection power in the counties. This zoning power has, in some instances, been held to include the ability of the county to prohibit the extraction of any natural resources.

All three levels of regulations appear adequate when viewed merely as a mechanism for permitting geothermal exploration and protecting against immediate environmental damage. Any search for proper regulatory regimes must achieve a delicate balance between encouraging investment of private capital to assume exploration risks and planning and coordinating, which will be needed to integrate geothermal resource development into California's complex power and water generation and consumption patterns. For the county, this may mean planning not only the location of geothermal development but also anticipating resulting land use changes across the entire spectrum. Electric energy production from geothermal resources utilizes a relatively large surface area of land per kilowatt unit produced. Thus, land uses compatible with geothermal energy production will need to be determined if multiple use is to be made of the surface.

Jurisdictional Questions

Geothermal resources, like oil resources, by their nature are likely to be defined in terms of reservoirs. These reservoirs, however, could underlie a combination of federal, state, county, or private land. Who will be responsible for management of single geothermal reservoirs that lie under lands controlled by separate jurisdictions?

The California Geothermal Resources Act of 1967 is cast in terms of state control over geothermal development on both federal and nonfederal lands within the State. On the other hand, Section 23(b) of the Geothermal Steam Act of 1970 (84 Stat. 1573, 30 U.S.C. 1022(b)) provides that the right to develop and utilize geothermal steam and associated geothermal resources underlying lands owned by the United States may be acquired solely in accordance with the provisions of this act. This section appears to preempt state and local authorities from legislating with respect to the acquisition of rights to develop and utilize geothermal resources on the federal lands. Unless this jurisdictional dispute is resolved, unnecessary duplication and inconsistencies may result in states like California, which have established and functioning state regulatory authorities.

In addition to the state-federal jurisdiction problem and the mingling of federal, state, and private lands above a reservoir, geothermal development may create intrastate, interstate, and international geothermal reservoirs in the Imperial Valley. Development has already taken place on the Mexican side at Cerro Prieto. Geothermal reservoirs are unlikely to respect political boundaries, and each reservoir may require a different approach before unitary development is feasible.

Although the basic framework for each regulatory level has now been set up, the major missing component is machinery to accomplish coordinated planning and regulation on a team basis. Any legal or institutional regime proposed to manage development must contain the flexibility to bridge political boundaries to bring together the various entities involved in particular reservoirs.

Consideration should therefore be given to a functional management scheme that would satisfy needs of federal, state, and local governments to exercise control over their respective lands and interests, yet not force one to yield its jurisdiction to the other. Such an arrangement now exists for water development through such federal-state institutions as the river basin commissions. A study to determine if some management control device along these lines can be established may be warranted. Such a mechanism might also facilitate the incorporation of the multipurpose applications of the basic resource.

California, with the passage of AB 1575 (Stats. 1974, Chap. 276), will have a potential vehicle for the coordination of research and development programs in the State Energy Resources Conservation and Development Commission. An entity such as the commission, which will play a major role in the planning for development of geothermal resources, will need to develop the capability to deal with the three multipurpose components of the geothermal resource--power, water, and minerals. It is clear that geothermal power production will have far-reaching effects on the water resources of the State, including the quality of its waters. This will hold true whether geothermal resources are ultimately defined as water or the water is merely viewed as the carrier, or medium, for the heat. Planning for such power production can thus not be undertaken without a thorough understanding and assessment of water resources factors. Water will be needed in the production cycle, reinjection technology, and the cooling cycle. The quantity and quality of water

utilized will depend upon the sources available, the technology employed, and the needs and characteristics of the reservoir in question. Some reservoirs may permit the mining of water without subsequent reinjection. Other reservoirs are likely to involve injection of water from outside sources. The number of possible combinations defies description, but water resources will play a significant role in the production of electric power without the additional component of fresh water production.

At this stage in the development of geothermal resources, it appears that power production, fresh water production, and mineral recovery may prove compatible in some reservoir situations. The feasibility of such multiple product utilization is largely influenced by the nature of the resource found and environmental and economic considerations. However, because we are dealing with a resource that, in large measure, will not be subject to open market conditions, the need for long-term planning becomes especially important. The Legislative may wish to reserve to itself the ability to influence utilization of the multiple components of the resource. Like the Federal Geothermal Steam Act of 1970, which reserves to the Secretary of the Interior the right to require production of more than one component of the resource, the State of California may also wish to establish a vehicle whereby resource utilization can be influenced on both state lands and private property.

Problems in the Market Place

A significant deterrent to the development of geothermal resources has been the curious institutional structure created by the resource. Although the technology and physical characteristics of geothermal resources dictate that resource assessment and development be integrated with power-generation, this integration has been hindered because the resource development industries and the utilities have completely different financial policies and regulations. The development of geothermal steam, however will necessitate expensive and risky drilling, and electric utilities are understandably reluctant and hesitant to underwrite risky exploration.

A second obstacle to more rapid development of geothermal resources is the long unproductive period between exploration and the establishment of the geothermal reservoir to get geothermal power on the line. The ability and desire of individual companies to invest in leases, to invest in drilling costs, and to hold until some buyer can be found are limited.

Because of inherent requirements, utilities need some assurance of the quantity and life expectancy of the reservoir before commitments can be made. Thus, the developer will need to spend substantial capital in proving the capacity of the total field. Unlike oil or hard minerals, the discovery of steam or hot water in one well does not guarantee marketability of the resource.

Geothermal operations are somewhat of a gamble at this point, not only as to the likelihood of finding a sufficient quantity or quality to be marketable, but also as to the likelihood of finding a market. When discoveries

are made involving a geothermal resource capable of power production, a publicly-owned or privately-owned power supplier must be found who can buy and distribute the power. Power suppliers must have known and proved sources of power on the drawing boards to be scheduled as much as 10 or more years in advance. The natural and understandable tendency is to lean toward conventional sources, manmade and in determinable increments -- hydroelectric, hydrocarbon fuels, and nuclear energy. This factor requires that the geothermal explorer or developer prove up sufficient quantities of the energy resource to compel power suppliers to weigh the relative cost to their consumers.

Many factors combine to make geothermal development susceptible to antitrust scrutiny. First, power will be produced in large measure by publicly-owned and privately-owned utilities which, under our legal system, are granted special privileges, encouraging exclusive distribution systems. Second, geothermal resources are geographically restricted to their source for energy production. Third, the suppliers of geothermal steam or water are likely to be oil companies with substantial land or mineral ownership in a given geothermal reservoir area. Finally, the market for electricity is more closely regulated than is the market for fossil fuels. The California Legislature may wish to study these factors.

In an effort to encourage private and public entities develop practical and environmentally acceptable processes for producing electrical energy from geothermal resources, the Geothermal Energy Research, Development, and Demonstration Act of 1974 (88 Stat. 1079) was passed by the Congress. As one of its provisions, it would guarantee a portion of the loans required for commercial development.

Environmental Considerations

In addition to technological, economic, and legal considerations in geothermal resource development, certain environmental considerations are associated with utilizing this resource. Existing land use patterns will be affected with the introduction of industrial operations into nonindustrial areas. Geothermal development is expected to result in restricting the use of land surface in the immediate vicinity of wells, pipelines, power plants, and related surface structures. Environmental groups have expressed concern that the aesthetic qualities of an area will be harmed by such geothermal appurtenances.

Waste water disposal problems will need careful attention. If large quantities of fluids are removed, possible subsidence and its effects must be considered. To prevent the contamination of ground and surface water, reinjection of used geothermal fluid is expected to be standard operating procedure in geothermal fields. The impact of such reinjection upon reservoir life and seismic conditions is unknown.

Air and noise pollution, although technically controllable, will need special attention.

In discussing environmental effects, it should be pointed out that development and production of the resource is broken down into six or more distinct phases: exploration, test drilling, production testing, field development, power plant and power line construction, and full scale operation.

One of the legislatively designated methods by which the environmental considerations are to be assimilated into the decision-making process, both at the federal and state levels, is the preparation of environmental impact statements. The U. S. Department of the Interior has prepared such an environmental impact statement on the geothermal leasing program on federal land, in accordance with the requirements of the National Environmental Policy Act.

It is probable that an additional environmental impact statement will need to be prepared after completion of the exploratory phase to cover one or more of the subsequent phases. To predict with any certainty the legal requirements as to frequency, timing, scope, and content of environmental impact statements is impossible because many of the questions will continue to be litigated. It is, however, safe to predict that geothermal development, like any other energy project with environmental consequences, will face increased responsibilities with regard to environmental impact statements.

Under California law, the State Lands Commission is required to prepare an environmental impact statement and to hold public hearings before it can lease state lands for geothermal exploration or development. The commission will face a question similar to that of the U. S. Department of the Interior in attempting to assess whether or not any further statements need to be prepared after exploration.

The California Environmental Quality Act of 1970 (California Public Resources Code Sections 21000-21151) requires environmental impact statements to be prepared for all government-funded or approved projects that may have significant effects on the environment.

Because the drilling of geothermal wells is subject to state and local regulations, an environmental impact report may be required for permits for such well drilling. Depending upon the jurisdiction, some of these drilling permits may be considered ministerial rather than discretionary and thus exempt from the California Environmental Quality Act of 1970.

In preparing environmental impact reports under the California law, the information contained in a federal environmental impact statement under the National Environmental Policy Act can be utilized.

If interested private and governmental entities could find a mechanism to finance the preparation of master environmental impact reports for particular geothermal regions in California, the preparation of subsequent reports for particular projects would be greatly facilitated. Such

master environmental impact reports cannot and should not substitute for the documenting of environmental effects of a particular development, but would result in better project reports.

Furthermore, master environmental impact reports on the geothermal energy alternative can put this energy source in its proper perspective. To understand properly the impact of the production of electric power on the environment, it is necessary to evaluate more than just the power plant, whether it is geothermal, nuclear, or fossil-fueled. The entire fuel cycle from mining, processing, transportation, and the disposal of spent wastes must be considered.

Appendix B

BIBLIOGRAPHY

Appendix B

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Allen, Donald R. "Earth Heat Tapped for Geothermal Development". Public Power, Vol. 29, No. 6, pp. 35-39. November-December 1971.

----. "Legal and Policy Aspects of Geothermal Resources Development". Water Resources Bulletin, American Water Resources Association, Vol. 8, No. 2, pp. 250-256. April 1972.

Anderson, David M. "Geothermal Development in California". Society of Petroleum Engineers of AIME, presented at 43rd Annual California Regional Meeting. November 1972.

----. "Geothermal Development in California: California Past, Present, and Future". California Department of Conservation, Division of Oil and Gas. Summary of Operations, Vol. 58, No. 1. 1972.

Austin, A. L., et al. "The Total Flow Concept for Recovery of Energy from Geothermal Hot Brine Deposits". Lawrence Livermore Laboratory, University of California, Livermore, California. April 3, 1973.

Austin, Carl F. "Selection Criteria for Geothermal Prospects". (preliminary) U. S. Naval Ordnance Test Station, China Lake, California. May 1965.

----. "Undersea Geothermal Deposits--Their Selection and Potential Use". U. S. Naval Ordnance Test Station, China Lake, California. July 1966.

Barnea, Joseph. "Geothermal Power". Scientific American, Vol. 226, No. 1, pp. 70-77. January 1972.

Brooks John W., Jr. "Legal Problems of the Geothermal Industry". Natural Resources Journal, Vol. 6, No. 4, pp.511-541. 1966.

California Department of Conservation, Division of Mines and Geology. "Geothermal Resources". Mineral Information Service, Vol. 21, No. 2. February 1968.

California Department of Conservation, Division of Oil and Gas. "California Laws for Conservation of Geothermal Energy". 1965.

----. "Geothermal Hot Line: Special K.G.R.A. Issue". For the California Geothermal Resources Board. July 1971.

California Department of Water Resources. "Crustal Strain and Fault Movement Investigation, Faults and Earthquake Epicenters in California". Bulletin No. 116-2. 1964.

----. "Investigation of Geothermal Waters in the Long Valley Area, Mono County". July 1967.

----. "Geothermal Wastes and the Water Resources of the Salton Sea Area". Bulletin No. 143-7. February 1970. (Reprinted June 1972).

California Department of Water Resources and California Department of Conservation, Division of Mines and Geology. "Geothermal Power in California". A response to Senate Resolution No. 138 relating to the use of geothermal power for the transportation of water over the Tehachapi Mountains. December 1966.

California Legislature. "California's Geothermal Resources". The Joint Legislative Committee on Tidelands. Reports to the 1967 Legislature.

----. "Geothermal Resources: Foundation for a Potentially Significant New Industry in California". Senate Permanent Factfinding Committee on Natural Resources. Fourth progress report to the Legislature. 1967 Regular Session.

----. Senate Bill No. 169. Geothermal Resources Legislation. 1967.

California Resources Agency. "Compendium of Papers, Imperial Valley--Salton Sea Area, Geothermal Hearing". Sacramento. October 1970.

----. "The Economic Potential of Geothermal Resources in California". January 1971.

Colorado River Board of California. Need for Controlling Salinity of the Colorado River". August 1970.

Comision Federal de Electricidad. "Cerro Prieto, Energia del Subsuelo". 1971. (English and Spanish).

Coplen, Tyler B. "A Geothermal Resources Reconnaissance of the Imperial Valley and Surrounding Area, Utilizing the Sodium-Potassium-Calcium Geochemical Exploration Technique". Contribution 73-33, Institute of Geophysics and Planetary Physics, University of California, Riverside. 1973.

Coplen, Tyler B., et al. "Preliminary Findings of an Investigation of the Dunes Anomaly, Imperial Valley, California". A joint study by the California Department of Water Resources and the Institute of Geophysics and Planetary Physics of University of California, Riverside. 1973.

Diblee, T. W., Jr. "Geology of the Imperial Valley Region, California". California Division of Mines. Bulletin No. 170, Geology of Southern California, Chapter II. 1954.

Dutcher, L. C., et al. "Preliminary Appraisal of Ground Water in Storage with Reference to Geothermal Resources in the Imperial Valley Area, California". Prepared in cooperation with the U. S. Bureau of Reclamation. U. S. Geological Survey Circular 649. 1972.

Federal-State Technical Group, Salton Sea Investigation. "Salton Sea Project, California: Reconnaissance Investigation". August 1969.

Godwin, L. H., et al. "Classification of Public Lands Valuable for Geothermal Steam and Associated Geothermal Resources". U. S. Geological Survey Circular 647. 1971.

Goldsmith, M. "Geothermal Resources in California: Potentials and Problems". EQL Report No. 5. California Institute of Technology, Environmental Quality Laboratory. December 1971.

Grose, L. Trowbridge. "Geothermal Energy: Geology Exploration and Developments". Mineral Industries Bulletin, Parts I and II, Vol. 14, No. 6, and Vol. 15, No. 1. November 1971 and January 1972.

Horvath, Joseph C., and Chaffin, Robert L. "Geothermal Energy. Its Future and Economics". Atlanta Economic Review, Vol. 21, No. 12, pp. 16-33. December 1971.

Imperial County Economic Development Commission. "Overall Economic Development Plan for County of Imperial, California". December 1966.

Imperial Valley Development Agency. "Imperial County Geothermal Resources Development Project". Report No. 3. February 1972.

Koenig, James B. "Geothermal Resources in California: A Status Report". California Division of Mines and Geology, Mineral Information Service, Vol. 19, No. 6. June 1966.

----. "The Salton-Mexicali Geothermal Province". California Division of Mines and Geology, Mineral Information Service, Vol. 20, No. 7. July 1967.

----. "Geothermal Exploration in the Western United States". Geothermics, Special Issue No. 2. 1970.

Kruger, Paul, and Otte, Carel. "Geothermal Energy: Resources, Production, Stimulation". Stanford University Press, Stanford, California. 1973.

Laird, Alan D. K., et al. "Ranking Research Problems in Geothermal Development". Research and Development Progress Report No. 711. U. S. Department of the Interior. August 1971.

McNitt, James R. "Exploration and Development of Geothermal Power in California". Special Report 75. California Division of Mines and Geology. 1963.

Meidav, Tsvi, and Rex, Robert W. "Geophysical Investigation for Geothermal Energy Sources, Imperial Valley, California: Phase I: 1968 Field Project". Technical Report No. 3. Institute of Geophysics and Planetary Physics, University of California, Riverside. July 1970.

Obras Geotermicas. "Potable Water Plant of Cerro Prieto, Mexicali, B. C.". May 1971. (English and Spanish).

Ogawara, Yohiko. "Geothermal Power Generation in the Limelight". Nikkei Business Magazine, pp. 96-98. May 1971.

Poland, J. F. and Davis, G. H.. "Land Subsidence Due to Withdrawal of Fluids". Geological Society of America, Reviews in Engineering Geology II, pp. 187-269. 1969.

Rex Robert W. "Investigation of the Geothermal Potential of the Lower Colorado River Basin: Phase I--The Imperial Valley Project". Institute of Geophysics and Planetary Physics, University of California, Riverside. No date.

----. "Investigation of Geothermal Resources in the Imperial Valley and Their Potential Value for Desalination of Water and Electricity Production". Institute of Geophysics and Planetary Physics, University of California, Riverside. June 1970.

Rex, Robert W., et al. "Cooperative Geological-Geophysical-Geochemical Investigations of Geothermal Resources in the Imperial Valley Area of California". University of California, Riverside. July 1971.

----. "Research Proposal to the National Research Foundation: Origin and Characteristics of a Major Hot Water Geothermal System in the Imperial Valley of California". 1972.

----. "Research Proposal to the National Research Foundation: Geological-Geochemical-Geophysical Investigations of the Recognized Geothermal Area in the Imperial Valley of Southern California". 1972.

Scott, Stanley, and Wood, Samuel E. "California's Bright Geothermal Future". Cry California: The Journal of California Tomorrow, Vol. 7. No. 1, pp. 10-23. 1971.

United Nations. "Proceedings of the United Nations Conference on New Sources of Energy". Vol. 2, Geothermal Energy: I. August 1961.

----. "Geothermics: Proceedings of the United Nations Symposium on the Development and Utilization of Geothermal Resources". Vol. 2, Part I. September-October 1970.

U. S. Bureau of Reclamation. "Geothermal Resources Investigations, Imperial Valley, California: Status Report". April 1971.

----. "Geothermal Resources Investigations, Imperial Valley, California: Site Location Report, Deep Geothermal Test Well". October 1971.

----. "Geothermal Resources Investigations, Imperial Valley, California: Development Developmental Concepts". Principal cooperator: U. S. Department of the Interior, Office of Saline Water. January 1972.

----. "Geothermal Resources Investigations, Imperial Valley, California: Colorado River Water Quality Improvement Program". February 1972.

U. S. Department of the Interior. "Environmental Impact Statement for the Geothermal Leasing Program". (Draft). September 1971.

U. S. Geological Survey. "Thermal Springs of the United States and Other Countries of the World: A Summary". Geological Survey Professional Paper 492. 1965.

University of California Riverside. "Geothermal Resources Development in California: Imperial Valley Potential". Vols. I and II. Prepared for Joint Committee on Public Domain, California State Legislature. November 1972.

Werner, Sanford L., and White, Charles R. "History and Development of Geothermal Resources in Imperial Valley". Presented at the 16th Annual Meeting of the Association of Engineering Geologists. October 25, 1973.

White, Donald E. "Geothermal Energy". U. S. Geological Survey Circular 519. 1965.

White, D. E., et al. "Vapor-Dominated Hydrothermal Systems Compared with Hot-Water Systems". Economic Geology, Vol. 66, pp. 75-97. 1971.